普通高等教育“十三五”规划教材

机械类专业英语应用教程

马庆芬　刘培启　主编

机械工业出版社
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机械工业出版社

本书的目的是使读者掌握机械类专业英语的基本知识、主要学习方法和技巧，培养和提高读者阅读、翻译专业英语文献资料及综合运用专业英语的能力。本书设置了理论和实践两个版块，可满足以学生为主体的课堂设计和情景教学。本书共15章，分为四部分：专业英语基础知识、阅读理解、口语训练和团队合作，以及写作训练，不仅提供了机械制图、机械设计、机械制造等多种机械类专业知识的阅读素材，配备了难句解析和专业词汇释义，还详解了专业英语应用中涉及的阅读、翻译、口语、写作等方面的方法与技巧。此外，本书在附录中还提供了词汇表、国际机械工程相关学术组织和国内外机械工程相关学术会议的列表，方便读者使用。

本书可作为机械类专业及各种机械相关专业的专业英语教材，也可以供机械工程相关领域的工程技术人员参考使用。

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前言

《大学英语教学大纲》(修订本)指出：专业英语是大学英语教学的一个重要组成部分，是促进学生完成从学习过渡到实际应用的有效途径。专业英语也是专业知识教学的延伸，要求学生学会从英语角度学习、理解专业知识，能够跟踪相关学科的国际发展前沿，在各种国际专业领域或行业的交流场合中熟练运用专业英语。因此，对于学习者而言，学习专业英语的目的不仅是掌握专业词汇、具备阅读和理解专业英语的能力，更重要的是提高专业英语的实战能力，即具备专业领域的英语沟通能力（包括听、说），能够熟练阅读国外相关的专业文献并准确理解和翻译，同时还需具备一定的科技英语写作能力。基于此，编者们从实践角度出发编写了本书，以满足高等院校机械工程各专业学生专业英语的学习、实践需求。

本书涉及的内容包括理论和实践两个版块。理论版块为本书第1部分，系统地介绍了专业英语的特点和专业英语翻译方法，以帮助学生准确理解专业英语。实践版块是本书的特色所在，为本书第2~4部分。第2部分提供了全面的英文原文阅读素材，来源于国外经典的相关专业著作，内容全面，涉及机械制图、力学基础、机器与零件设计、工程材料及热处理、各种制造技术等方面。第3部分旨在提高学生在国际专业领域交流场合中的表达能力，包括英文面试常用表达、英文报告设计方法及国际学术会议常用表达。第4部分侧重于学生专业英语写作能力的培养，介绍了英文科技论文和其他应用文体的写作方法。

本书不仅系统地阐述了专业英语的理论知识，还提供了多样化的实践素材。因此通过学习本书，学生不仅可以学到专业英语的基础知识，还可以根据本书内容在课堂上或自发地进行专业英语的实践，在实践中提高专业英语的运用能力，为今后的学习和工作打下良好的基础。

参加本书编写工作的有：马庆芬（主编，海南大学，负责大纲编写和统稿，以及编写第12~15章）、刘培启（主编，大连理工大学，负责编写第9、10章）、何文晋（副主编，海南大学，负责编写第6、7章）、蒋静智（副主编，河北科技大学，负责编写第1、2章）、邹媛媛（副主编，沈阳建筑大学，负责编写第8章）、沈仙法（副主编，三江学院，负责编写第5、11章和附录一）、樊军庆（参编，海南大学，负责编写第4章）、文伟（参编，海南大学，负责校稿和纠错）和李萌（参编，海南大学，负责编写第3章和附录二、附录三）。

本书由大连理工大学胡大鹏教授担任主审。胡教授为本书提出了很多中肯的修改意见，在此表示衷心感谢！

由于编者水平有限，书中难免有不足和欠妥之处，恳请广大读者批评指正。

编　者

目录

Fundamentals of Special English

Part Ⅰ 专业英语基础知识

本部分介绍专业英语基础知识，包括专业英语的特点和专业英语的理解与翻译。

本部分侧重理论学习，目的是使学生了解专业英语的特点、掌握专业英语的理解和翻译方法，为阅读英文专业文献或教材、准确翻译以及专业英语的写作打下良好的基础。

Unit 1

专业英语的特点

1.1 概述

当今社会，科学发展日新月异。作为一名科技人员，除应具备扎实的专业知识外，还应具备良好的英语水平。学好英语，尤其是与本专业知识紧密相关的内容，对于及时掌握本学科发展动态、加强国与国之间的信息和学术交流以及提高自己的科学研究水平，都是十分重要的。

通常，对把英语作为外语的学习者而言，英语可分为普通英语、科技英语和专业英语等。当然，也可把专业英语看成是科技英语的一个重要组成部分。普通英语（General English，GE），又称日常英语，是传统意义上的英语。科技英语（English for Science and Technology，EST）分离于普通英语，是科技发展的需要，是专业英语发展初期的重要表现形式，但其专业色彩并不浓厚。专业英语（Special English），又称专门用途英语（English for Special Purpose，ESP），是随着新兴学科的不断涌现和专业分工的日益细化，在科技英语的基础上逐步形成的。

1.1.1 什么是专业英语？

到底什么是专业英语？目前还无明确统一的定论，但可以明确的是专业英语是一种方法。《大学英语教学大纲》（修订本）指出：专业英语是大学英语教学的一个重要组成部分，是促进学生完成从学习过渡到实际应用的有效途径。该课程设置的主要目的是跟踪相关学科的国际发展前沿，促进相关学科课程教学与国际接轨，同时培养具有一定国际竞争能力的相关专业的高级人才。对于学习者而言，学习专业英语的目标，是在了解专业英语的特点的基础上，掌握一定量的专业词汇，通过训练提高专业领域的英语沟通能力（包括听、说），能够熟练阅读国外相关的专业文献并准确理解翻译，同时还需具备一定的科技英语写作能力。

专业英语是在自然科学和工程技术的专业领域中使用的一种英语文体。它是在专业技术的不断发展中逐渐形成并与专业技术同步发展的。专业英语的表述必须能客观、严谨地反映和阐述科学技术中的理论、技术、实验、现象等，因此专业英语除了包含一些实验数据、公式推导和数学符号以外，在词汇含义、语法结构、句型使用和修辞手法等方面与日常英语、文学英语有不同的特点。这诚如著名科学家钱三强指出的：专业英语“无论在语法结构或词汇方面都逐渐形成它特有的习惯用法、特点与规律”。不学习和掌握这些特点与规律，就很难搞好专业英语的阅读、翻译和写作。

1.1.2　学习专业英语的重要性

机械工程学科毕业生的一个重要发展方向就是成长为一名优秀的机械工程师。而很多机械工程师虽然能够熟练地运用专业知识解决工程实际问题，却由于不重视英语的学习因而不具备专业英语的沟通、运用能力，而使自身的发展、晋升受到了限制。英语是国际合作交流的基础，在全球经济一体化进程的推动下，各国之间政治、经贸往来和科技合作日益频繁，对精通英语及专业技术人员的需求不断增加，因此专业英语是优秀机械工程师的必备技能。具体来说，学习专业英语的重要性主要体现在以下几方面：

1. 有利于学生自身能力的提升

首先，专业英语对提高学生的英语水平有很大的帮助。专业英语是大学英语课程的延伸，为学生们提供了继续学习英语的机会，可以帮助备考全国大学英语四级、六级以及研究生英语入学考试。其次，专业英语有利于提高学生的综合素质。通过专业英语的学习不仅可以巩固专业知识、学习专业词汇，更重要的是在学习训练的过程中拓宽了自己的专业视野，有助于了解国际专业领域的前沿动态，并提高自己的阅读、写作、听说等英语沟通技能。最后，专业英语有利于学生的进一步深造。打好专业英语的基础对于研究生期间的学习会起到事半功倍的效果。良好的英文文献阅读和写作能力会使科研工作的开展更加顺利，良好的英语听说沟通能力有利于学术交流和出国进修。

2. 有利于专业领域前沿信息的获取

随着机械工程学科的不断发展和新技术的广泛应用，学习机械工程专业英语的过程也是吸取国外先进知识的过程。因为许多专业领域的文献和资料都是用英文书写的，只有学好专业英语才能读懂自己专业方面的英文文献，才可能了解专业领域的最新研究成果，才能使自己的专业视野跟上时代的步伐。

3. 有利于科研成果展示

科研成果的发表是科学研究的必经之路，尤其在国际领域发表高层次的成果才能得到专业界肯定。只有具备优秀的专业英语写作能力，才能将科研成果充分地在世界范围展示，获得认可的同时得到与国际同行交流的机会，从而找出科研过程存在的问题、拓宽科研思路、提升科研水平。

4. 有利于学术交流、促进国际合作

除了具备良好的英文阅读和写作能力，专业英语的听说也是学术交流的必备技能。在国际会议上做报告时，流利的英语表达能力能够帮助自己建立自信，提升自身科研成果的信服程度；自如地交流能够促进学术沟通，强化交流效果。成功的学术交流还会促成国际合作，促进科研成果迈出国门、走向世界范围的产业化。

1.1.3　本书的主要内容及使用建议

1. 本书的主要内容

本书的主要内容分为四大部分，下设 15 章。

第一部分介绍专业英语基础知识（Fundamentals of Special English），包括专业英语的特点和专业英语的理解与翻译。

第二部分为第一个专业英语实践环节——阅读理解（Reading and Comprehension）。文字

摘自多部原版英文著作，内容全面，涉及机械制图、力学基础、机器设计、零件设计、工程材料、基本制造技术及机器人等方面的专业知识。书中还对疑难句子进行了释疑，并且提供了主要专业词汇的释义。

第三部分为第二个专业英语实践环节——口语训练和团队合作（Oral Practices and Team Working）。该部分介绍了英语面试常用表达、英文学术报告设计方法以及国际学术会议交流用语，辅助情景教学，是本书最大的特色所在。

第四部分为本书设置的第三个专业英语实践环节——写作训练（Writing Practices），介绍了英语科技论文及应用文体的写作方法。该部分内容可根据学生不同的英语水平因材施教。

2. 使用建议

（1）第一部分的学习侧重理论　该部分的学习目的是使学生了解专业英语的特点、掌握专业英语的理解和翻译方法，为阅读英文专业文献或教材、准确翻译以及专业英语的写作打下良好的基础。

（2）第二部分的学习侧重实践——阅读能力锻炼和翻译能力培养　通过该部分的学习，学生应掌握较为全面、重要的专业词汇，在不断的阅读中体会专业英语与普通英语文体的区别，消化专业英语的特点，最重要的是结合本书第 2 章所学的方法锻炼专业英语的阅读能力、提升理解翻译的准确度。

学习过程可包括课堂精读和课后自学两个部分。

1）课堂精读是在老师的引导下训练阅读能力，进行多种翻译实践；教学过程中要经常更换教学主体，增强课堂互动，可采用即时提问、同学互问互答、互相纠错、学生上讲台讲解部分知识等方式，使学生能够集中精力，不走神、不厌学。

2）课后自学素材可取材于本书也可以由学生自己查找文献，其目的是巩固课堂教学效果，通过不断练习提升阅读和翻译水平，同时在泛读专业资料或文献的同时开阔视野。

（3）第三部分的学习侧重实践——英语沟通能力培养和协作精神培养　学习时可以参考书中介绍的英语面试常用表达、英文学术报告设计方法以及国际学术会议交流用语，鼓励学生设计与专业领域相关的情景主题、自主发挥完成情景细节与表演，提升口语表达、听力水平及培养团队合作精神。以下几种情景主题可供参考：

1）情景一：国际学术会议。

国际学术会议为我们提供了了解学科科研动态、展现自身研究成果的平台。在参会时，很多中国学生甚至是老师在运用英语获取专业信息或交流方面都存在张不了口、有观点却无法表达的困难。只有掌握学术会议各个阶段及各个角色的常用英语表达，才能在各个环节自信、熟练地交流。学生可以自由分组搭配，扮演大会主持人、报告人（包括教授、技术人员、管理人员等）、提问者等实际角色。通过多次、各种学术会议的模拟，使学生掌握该场合的一些专用表达，以便今后在真正的学术会议上更好地明确会议安排，了解更多行业动态，并能正确、自信地表达自己的观点。

2）情景二：学术报告。

大学期间，学生大部分课堂学习都是被动接受知识，很少有表现自己的机会。而在毕业后，想获得很好的工作机会或在工作中表现出色，必须学会展示自己。在全班同学面前做报告就是学习如何展现自己或成果的良机。让学生按照自身的兴趣，自主分组，设计学术报告

并且每个人都需要表现。报告中鼓励学生借助多种方式为报告增色，如剪辑合成视频、制作实物、制作动画效果等，也可提升学生的综合能力。除了做报告外，每个同学还要听取其他同学的报告，并在现场提出问题，锻炼了学生们的英语听、说和沟通能力，并从英语角度拓宽了他们的专业视野。

在每次报告结束后，教师对同学们的报告进行总结，结合报告实际情况讲解专业英语要点及做学术报告的技巧。通过做英文学术报告和老师指导，学生们学会了如何搜集、组织和整理素材，如何用各种形式做好展示，如何进行英语表达。学术报告拓宽了学生的专业英语视野，提高了创新能力，而且最重要的一点是提高了他们的团队合作意识和能力。

3）情景三：科技类电视节目。

科技类电视节目也是一个情景教学的不错切入点，因为它既来源于实际生活又与专业息息相关，有助于普通口语、听力的锻炼和专业英语知识的运用。正是它的综合性对学生提出了不小的挑战，选择这个主题的学生需具备较高的英语水平，通过精心设计和准备，才能给大家提供一个生动、流畅的电视节目。

4）情景四：入职、升学、出国面试。

入职面试往往会包含英文面试，外企可能是全英文面试。考研复试及出国留学面试也都需要不同程度的英语表达。不论是上述哪种面试，面试官都试图尽可能多地了解毕业生在上学期间的收获，其中权重很大的就是专业知识。以上提到的几类面试过程都是专业英语的运用过程。学生需结合专业所学准备英文自我介绍，具备足够的专业英语基础才能够理解面试官的专业问题并给出正确的答案。面试官是专业英语的熟练使用者，需要听懂并评判面试者的表达，与面试者进行流畅的沟通。鼓励学生扮演面试过程中的不同角色，不仅是一次很好的实践机会，也可以为今后真正的面试做准备。

（4）第四部分的学习侧重实践——英语写作能力的培养　该部分内容可根据学生不同的英语水平因材施教。对于英语基础薄弱的同学，侧重点是写作方法的了解和学习；对于英语基础较扎实的同学，可以在上述基础上进行科技论文写作的实战练习，撰写综述类或设计类英文文章。

（5）因材施教，分层次教学　目前，专业英语课程的教学方法对所有学生都一样，但不同的学生英语水平差别很大，相同的教学方法会使一部分基础较弱的学生感到无论如何努力都无法达到目的，从而产生厌学情绪；而基础好的学生会感觉课堂上的大部分内容是对以前内容的回顾和复习，从而对学习失去兴趣。因此，对学生的英语基础进行考核，提出分层次的教学要求，可以使各种英语水平的学生都能在学习过程中看到自己的进步，有助于提高学习积极性。

本书内容全面，可满足分层次教学的需求，对于不同英语基础的学生可以设置不同的教学目标。对于基础较差的学生，应该考核专业英语特点的学习、词汇的掌握情况以及英语专业知识的阅读理解；对于基础中等的学生，在上述内容的基础上，还可以引导他们阅读难度更高的英文科技文献，并做总结或报告，进一步提升英语运用能力；对于基础很好的学生，可以在上述内容的基础上让他们进行科技论文写作的实战练习，在大量查阅英文文献的基础上，撰写综述专题或设计类文章，此过程也可以由专业英语教师在课程结束后继续指导学生进行。

1.2 词汇特点

1.2.1 词汇分类

专业英语词汇可分为技术词汇、半技术词汇、特用词和功能词等。

1. 技术词汇（Technical Words）

机械专业英语大多涉及机械领域的相关专业知识，通常是用来说明机械本身的作用原理、已存在的规律或者该领域的新论点。其本有“量身定制”的专属术语和词汇，即专业词汇。这些词汇通常使用范围比较狭窄，但专用化程度高，词义单纯，严谨规范。例如：

◆ fuel & water separator——油水分离器
◆ turbocharger——涡轮增压器
◆ condensate drain valve——冷凝水排污阀
◆ thread strength class——螺纹强度等级
◆ superconductivity——超导性
◆ ferroaluminium——铁铝合金
◆ diathermometer——热阻测定仪
◆ mechatronics——机电一体化，机械电子学

2. 半技术词汇（Sub-technical Words）

半技术词汇是在各专业中出现频率都很高的词。这类词往往在不同的专业中有不同的含义。例如 conductor，energy，efficiency，field，force，load，operation，plant，power，reaction，revolution，register，solution，system，work 等。下面为其中一些词汇在不同的专业中有不同的含义的例子。

power——在日常英语中，表示“力量，权力”；在机械专业，表示“动力”；在电力专业，表示“电力”；在数学专业，表示“幂”；在物理专业，表示“功率”；在体育专业，表示“爆发力”。

reaction——在日常用语中，表示某人对某事的反应；在化学中，表示两种物质分子间的化学反应；在核物理中，表示原子核的链式反应；在土木工程中，表示反作用力。

register——在日常生活中，表示“登记簿，记录（员，表），挂号信”等；在电学中，表示“计数器，记录器”；在乐器中，表示“音域，音区”；在计算机中，表示“寄存器”。

solution——在数学中，表示“解法，解式”；在化学中，表示“溶解”。

3. 特用词（Big Words）

在日常生活中，为使语言生动活泼，常用一些短小的词或词组。而在专业英语中，为了准确、正式、严谨，不与其他词义混淆，往往选用一些较长的特用词。这类词在非专业英语中极少使用，但却属于非专业英语。

例如：在专业英语中，为避免引起歧义，用 complete 表示“接通”，因为 complete 词义单一，准确。

The circuit is then completed. 然后接通电路。

而不用 The circuit is then turned on. 这是因为 turn on 的词义较多，除了表示“接通

(入)”以外，还可表示如“（拧，旋）开，朝向，依靠（赖，据），攻击”等意义。

例如：The success of a picnic usually turns on（依赖）the weather.

The dog turned on（袭击）to me and bit me in the leg.

类似的特用词还有：

- 立刻——immediately—×—at once
- 可观的——appreciable—×—a lot of
- 足够的——sufficient—×—enough
- 确定——determine—×—find out
- 下降——depress—×—go down
- 保持——maintain—×—keep
- 插入——insert—×—push in
- 传递——transmit—×—send
- 颠倒——invert—×—turn upside/down
- 消耗——consume—×—used up

4. 功能词（Function words）

功能词包括介词、连词、冠词、代词等。它们在句子中提供十分重要的结构信号，对于理解专业内容十分重要。它们出现的频率极高。有统计数据表明，在专业英语中出现频率最高的十个词都是功能词，它们是（按出现频率高低顺序排列）the，of，in，and，to，is，that，for，are，be。

例如：It simply means that tool have softened to the point where the movement of the tool in relation to the work makes the tool too soft for efficient cutting.

上述例句中 29 个词中就有 14 个功能词。

1.2.2　词汇构成

英语的构词法包括转化法、合成法、派生或词缀三种形式。

1. 转化法（Conversion）

转化时词形一般不变（有时发生重音变化或尾音变化），只是词类发生转换。最常见的是，英语名词转译成汉语形容词，用作所修饰名词的前置定语。

例如：When the tanker reaches the refinery, its load of crude is pumped into the *refinery storage* tanks.

句中“*refinery*”，“*storage*”原均为英语名词，现转译为汉语形容词，做“tanks”的前置定语，则“the refinery storage tanks”意为“炼油厂储油罐”。句中“crude”原义为形容词“未加工的”，现转换为汉语名词“原油”。

此外，英语名词还可转换成动词。例如 melt 做名词意为“熔液”，转化为动词意为“熔化”；finish 做名词意为“光洁度”⊖，转化为动词意为“精加工，抛光”；alloy 做名词意为“合金”，转化为动词意为“使成合金”。

⊖ 在我国现行国家标准中，术语“光洁度”已被“粗糙度”（roughness）代替，但在英文文献中还会遇到。

2. 合成法（Composition）

由两个或更多的词合成一个词。合成词在英语中比较活跃。它由介词、名词、动词、副词、形容词等词组合而成。例如：

- ◆ wave + form→waveform（名词 + 名词）波形
- ◆ ball + bearing→ballbearing（名词 + 名词）滚珠轴承
- ◆ work + shop→workshop（名词 + 名词）车间
- ◆ tool + room→toolroom（名词 + 名词）工具室
- ◆ in + put→input（介词 + 动词）输入
- ◆ feed + back→feedback（动词 + 副词）反馈
- ◆ radio + photography→radiophotography（名词 + 名词）无线电传真
- ◆ white + wash→whitewash（形容词 + 名词）石灰水

3. 派生法（Derivation）

专业英语词汇大部分都是派生法构成的，即由词根（base）加上各种词缀（前缀（prefixes）和后缀（suffixes）来构成新词。了解并掌握一些常用的词缀，对学习英语词汇是有益的。常用的表示否定的前缀、名词前缀、形容词词缀和动词词缀如下：

（1）表示否定的前缀　常用的表示否定的前缀有 8 个，见表 1-1。

表 1-1　表示否定的前缀

词　缀	词　例
a-	asynchronous（异步的），asymmetric（不对称的）
ab-	abnormal（异常的）
dis-	disobey（不服从），dismount（拆除）
in-	injustice（不公正），inhomogeneous（不均匀的）
il-	illegal（非法的）
ir-	irrational（无理数），irrecognizable（不能辨认的）
im-	impossible（不可能的），imbalance（不稳定）
non-	noncontact（不接触），nondestructive（非破坏的）
un-	unwilling（不情愿的），unrenewable（不能回收的）

（2）名词词缀　常用的名词词缀有 24 个，其中有 16 个前缀，8 个后缀，见表 1-2。

表 1-2　名词词缀

词　缀	词　例
前缀	
auto-	automation（自动化），autoplotter（自动绘图仪）
inter-	interalloy（中间合金），intergrinding（相互研磨）
counter-	counteraction（反作用），countertorque（反力矩）
sub-	subway，submarine（潜水艇）
in-	intake［（水、气等）入口］，inlet（海湾，小港）
out-	outlet［（河流）出口］，output（产量，输出）
through-	throughput［生产量，（物料）通过量］
hyper-	hyperbar（高气压），hyperpressure（超压）

（续）

词缀	词例
前缀	
di-	diode（二极管），diphase（二相的）
tri-	triangle（三角），triode（三极管）
tele-	telescope（望远镜），telemeter（遥测表）
photo-	photoprocess（光学处理），photograph（照相）
micro-	microwave（微波），micrometer（微米）
ultra-	ultrasonic（超声波），ultralimit（超极限）
super-	superhardness（超级硬度）
holo-	holograph（全息照相），hololens（全息透镜）
后缀	
-ics	dynamics（动力学），statistics（统计学）
-cle	particle（粒子）
-ism	mechanism（机构）
-ist	scientist（科学家），artist（艺术家）
-scope	microscope（显微镜），telescope（望远镜）
-phone	microphone（话筒）
-logy	anthropology（人类学），technology（技术，工艺）
-ness	brightness（光亮），kindness（慈祥）

（3）形容词词缀　常用的形容词词缀有 14 个，其中 5 个前缀 9 个后缀，见表 1-3。

表 1-3　形容词词缀

词缀	词例
前缀	
-in	inadequate（不充分的），insufficient（不足的）
im-	immaterial（非物质的），impossible（不可能的）
ir-	irrational（不合理的），irresponsible（不负责任的）
un-	unchanged（未改变的），unstable（不稳定的）
super-	superficial（表面的），supersonic（超声的）
后缀	
-able，-ible	noticeable（显而易见的），negligible（可忽略的）
-ive	reactive（反应的），effective（有效的）
-ent，-ant	sufficient（足够的），vibrant（振动的）
-ing，-ed	cutting（切断），compressed（被压缩的）
-al	structural（结构的），critical（临界的）
-ar	circular（循环的），linear（直线的，线性的）
-ic	electronic（电子的），metallic（金属的）
-ous	synchronous（同步的），porous（多孔的）
-proof	fireproof（防火的），waterproof（防水的）

（4）动词词缀　常用的动词词缀有 14 个，其中 10 个是前缀，4 个是后缀，见表 1-4。

表 1-4 动词词缀

词缀	词例
前缀	
re-	reuse（重新使用），rechange（再变更），recall（召回）
over-	overwork（工作过度），overload（超载）
under-	under-load（负载），underpay（少付……工资）
dis-	disconnect（拆开），discharge（解雇）
de-	demagnetize（消磁），defreeze（解冻）
ab-	abjure（誓绝），abstain（戒除，弃权）
con-	confound（混淆，搞错）
ex-	exit（出口），external（外部的）
ob-	obstruct（阻塞，阻挡）
trans-	transform（转换，变换）
后缀	
-en	weaken（使变弱），harden（变硬），shorten（变短）
-fy	electrify（使电气化），purify（净化）
-ise	normalise（使正常化），energise（激励，通电）
-ate	integrate（使……完整），accelerate（使……加快）

1.2.3 词汇缩略

在英语中，缩略词通常具有简洁明了、容易记忆和便于读写的特点，因此，机械专业英语中经常大量使用缩略词。下文简要罗列了几种常见的缩略形式：

1. 首字词缩略词（Initialism）

由原词组的每个词的首字母组成，朗读应逐字母读出。例如：

NC　　Numerical Control 数字控制
PLC　　Programmable Logic Controller 可编程逻辑控制器
AC　　Adaptive Control/Alternating Current 自适应控制/交流电
AIEE　　American Institute of Electrical Engineers 美国电气工程师学会
FOPS　　Falling Object Protective Structure 落物保护装置
AGVS　　Automatic Guided Vehicle System 车辆自动导向系统
CAD　　Computer-Aided Design 计算机辅助设计

2. 首字母组合词（Acronyms）

把一个词组中的首字母拼凑成一个词，在朗读中视为一个单词发音，不要逐字母读出。

Laser　　light amplification by stimulated emission of radiation 激光
ROM　　Read Only Memory 只读存取存储器
RAM　　Random Access Memory 随机存取存储器

3. 截短词（Clipped Words）

为了方便，在发展过程中逐渐使用单词前几个字母来表示。

Kilo　　Kilogram 公斤
Lab.　　laboratory 实验室
Mach.　　machinery 机械，机构
Ref.　　reference 参考书目

4. 缩写词（Abbreviation）

etc.　　et cetera 等等
i. e.　　that is 即，也就是
e. g.　　for example 例如
vs.　　versus 对（比），比较
in.　　inch 英寸
ft.　　foot 英尺

1.2.4　数词、公式和符号

在专业英语中，为明确表达，还含有较多的符号、公式、方程等。

1. 符号

专业英语中常见符号见表1-5。

表1-5　专业英语中常见符号

符　号	意　义	符　号	意　义
∵	because	μp	microprocessor
∴	therefore	μc	microcomputer
≯	is not greater than	″	seconds, inches
≮	is not less than	°, ℃	degree, centigrade
>>	is much greater than	//	is parallel to
<<	is much less than	∑	the sum of
&	and	⊥	is perpendicular to
→	lead to	∬	double integral
≡	is identically equal to	∭	triple integral
∽	is similar to	¥	yuan
£	pound	#	number
∈	is member of set	$	dollar

2. 常用希腊字母

常用希腊字母读音见表1-6。

表 1-6 常用希腊字母读音

字母	英文读音	字母	英文读音	字母	英文读音
α	alpha	η	eta	ρ	rho
β	beta	θ	theta	σ	sigma
γ	gamma	λ	lambda	τ	tau
δ	delta	μ	mu	φ	phi
ε	epsilon	ν	nu	ψ	psi
ζ	zeta	π	pi	ω	omega

3. 数学符号

（1）分数、小数及百分比　分数、小数和百分比的读法见表 1-7。

表 1-7　分数、小数及百分比读法

符号	读法
1/3	a third, or one third
2/9	two ninths
0.2	zero point two
66.67	sixty-six point six-seven
0.3%	zero point three percent
8‰	eight permille

（2）符号与方程　符号与方程读法见表 1-8。

表 1-8　符号与方程读法

运算符号和关系	读法
$a=b$	*a* equals *b*; *a* is *b*
$a\neq b$	*a* is not equal to *b*
$a\pm b$	*a* plus or minus *b*
$a\approx b$	*a* is approximately equal to *b*
$a\geqslant b$	*a* is greater than or equal to *b*
$a\leqslant b$	*a* is less than or equal to *b*
$a\gg b$	*a* is much greater than *b*
$a\ll b$	*a* is much less than *b*
$a\nless b$	*a* is not less than *b*
$a\ngtr b$	*a* is not greater than *b*
a^2	*a* square, *a* squared, the square of *a*, *a* to the second power
a^3	*a* cube, *a* cubed, the cube of *a*, *a* to the third power
a^n	the *n*th power of *a*, *a* to the *n*th power
$\sqrt{a}$	the square root of *a*
$\sqrt[3]{a}$	the cube (third) root of *a*
$\sqrt[n]{a}$	the *n*th root of *a*

1.3 语法特点

1.3.1 被动语态的广泛使用

由于专业英语文献侧重叙事和推理，陈述的对象是客观事物。读者重视的是作者的观点、发明的内容以及获得的结果，而不是作者本人。因此在语言表述中必然较多地使用以客观事物为主体的被动语态。有统计数据表明，在专业英语中，被动语态的句子约占1/3～1/2，即使是主动语态，主语也常常是非动物的（inanimate subject）。这主要是因为在专业英语中，专业人员关心的是事实和行为，而不是行为者。同时，使用被动语态可以使句子更简明，还可以将重要的信息放在句首，可以一下子就能抓住读者的注意力。

例如：

① Springs are used as cushions to absorb shock.（强调主语，突出重要性）弹簧被用作吸收振动的缓冲器。

② Pressure control valves are used in hydraulic systems to control actuator force.（强调主语，突出重要性）在液压系统中，压力控制阀用于控制油缸驱动力。

③ When a force is applied to a material, it produces a stress in the material.（不需要指出动作的执行者）当给材料施加力时，就会产生应力。

④ Electrical energy can be stored in two metal plates separated by an insulation medium. Such a device is called a capacitor, and its ability to store electrical energy is termed capacitance. It is measured in Farads. 电能可以储存在被一绝缘介质隔开的两块金属板中，这样的装置被称为电容器，它储存电能的能力就被称为电容。电容的测量单位是法拉。

被动语态广泛用于表述规则、原理、过程、技术报告和说明书等。例如以下这段文字一共5个句子，共使用了5个被动语态。由此看出，在专业英语中，被动语态使用的频繁性。

The combustion of the mixture does not take place instantaneously. The spark ① **is** therefore **timed** to occur before the piston reaches top dead center, otherwise maximum pressure would not ② **be reached** in time. By the time the piston is at top dead centre, combustion is well underway and the expansion of the gases is beginning. Once combustion starts, it should ③ **be carried** through the mixture very rapidly, and this ④ **is assisted** by making the clearance space above the piston as small as possible, and by careful design of the cylinder head. Rapid propagation of the flame through the compressed gas ⑤ **is** also **assisted** by creating turbulence in the gas.

1.3.2 非谓语形式的广泛使用

在专业英语中，动词的非谓语形式应用广泛，这是因为专业英语要求准确、精炼，而动词的非谓语形式可以很好地实现这些要求。采用这一形式能用扩展的成分对所修饰的词进行严格的说明和限定，其中每一个分词定语都能代替一个从句，从而可使很长的句子匀称，避免复杂的主从符合结构，并省略动词时态的配合，使句子既不累赘又语意明确。

1. 动名词的使用

1）动名词构成的介词短语可取代状语从句或简化陈述句。例如：

In redesigning an experimental part for production, economical tolerances should be used. 为了生产而重新设计试件时，必须使用经济公差。

2）用动名词短语取代时间从句或简化时间陈述句。例如：

① The signal should be filtered before being amplified. 放大信号前，应先对其进行滤波。

② Once being placed in the sun, an object becomes hot. 物体放置在太阳下会变热。

③ Before designing a new electronic product we must do various experiments. 在设计一个新的电子产品之前，我们必须做各种实验。

3）用动名词短语做主语可以简化句子结构。例如：

① Changing resistance is a method for controlling the flow of the current. 改变电阻是控制电流的一种方法。

② Conducting electricity means the flow of electrons through an object. 传导电流意味着电子在物体内的流动。

2. 分词的使用

1）在专业英语中，分词短语被大量地用作定语、状语和独立分词结构带被动语态或主动态的关系从句，使句子结构得到简化。例如：

① The process is called dieless drawing, as the product being formed without direct contact with a die. 由于产品是在不与模具直接接触的情况下成形的，故称此工艺为无模拉拔。

② Originally designed for rapid, automatic production of screws and similar threaded parts, the automatic screw machine today plays a vital role in the mass production of a variety of precision parts. 自动螺丝车床最初是用来对螺钉和类似的带有螺纹的零件进行自动化快速加工的。现在，它在许多种类的精密零件的大批量生产中起着重要的作用。

2）分词独立结构，即：名词或代词 + 分词短语，是一种主谓结构，在句中的作用相当于并列分句或从句。例如：

Agitation is critical, the aim being to distribute silicon carbide particles homogeneously throughout the aluminum melt. 搅拌至关重要，其目的是将碳化硅颗粒均匀分布在整个铝液中。

3）分词独立结构前加 with（without）变成起状语作用的介词短语，用于当分词的逻辑主语与句子主语不一致的场合。

In the heat exchanger of blast furnace the air flows through the outside pipe, the gas through the inside pipe, with heat change taking place through the wall. 在高炉热交换器中，空气流过外管，燃气流过内管，热交换通过管壁进行。

3. 不定式的使用

不定式在专业英语中常用来替换表示目的和功能的从句，使句子结构简练。例如：

① The capacity of individual generators is larger and larger to satisfy the increasing demand of electric power. 单台发电机的容量越来越大，目的就是满足不断增长的用电需求。

② There is high requirement of skill in carrying out this operation to produce products with high performances. 进行这项操作时需要很高的技巧，以生产出具有高性能的产品。

4. 名词化结构

“表示动作意义的名词 + of + 名词 + 修饰语”叫作名词化结构。名词化结构具有文字明

了、用词简洁、结构紧凑、表意客观、信息容量大等特点，在专业英语中经常用它代替主、谓结构做各种句子成分，使句子结构简化。例如：

The ultrasonic metal inspection is the application of ultrasonic vibrations to materials with elastic properties and the observation of the resulting action of the vibrations in the materials. 金属超声波探伤是将超声振动施于具有弹性的材料，并观察振动在材料中产生的作用。

1.3.3 省略句使用频繁

专业英语为了简洁，有时省略句中的一些成分，如状语从句中的主语和谓语，关联词 which 或 that 引导的定语从句中的关联词和从句中的助动词等，还常用介词短语替代从句。例如：

① If possible, the open-loop control approach should be used in this system. 可能的话，这个系统应该使用开环控制方法。

② The device includes an instrument transformation and a relay system with (which has) two circuits in it. 这个装置包括一个互感器和一个有两个电路的继电器系统。

常见的省略句型如下：

As described above	如前所述
As explained before	前已解释
As already discussed	前已讨论
As indicated in Fig. X	如图 X 所示
As previously mentioned	前已提到
If possible (necessary)	如果可能（必要）的话
If so	倘若如此
When necessary (feasible, needed)	必要时（可行时，需要时）
Where feasible (possible)	在可行的（可能的）情况下

1.3.4 It 句型和祈使句使用频繁

1. It 句型

It 句型中 it 充当形式主语，避免句子“头重脚轻”。

1）It 句型常用于一些固定句型，翻译时不加主语。例如：

It is supposed that...	据推测……
It is hoped that...	希望……
It is said that...	据说……
It must be admitted that...	必须承认……
It must be pointed out that...	必须指出……
It will be seen from this that...	由此可见……

2）有时翻译时添加主语更为顺畅。例如：

It is suggested that...	有人建议……
It is stressed that...	有人强调说……

It is generally considered that... 大家认为……

It is told that... 有人曾说……

It is well known that... 众所周知……

It is believed that... 有人认为……

It is found that... 人们已经发现……

3）一些非被动句也可以用 It 句型表达。例如：

It is a fact that... 事实上……

It is apparent that... 很明显……

It goes without saying that... 不言而喻……

It follows that... 由此可见……

It is common knowledge that... 众所周知……

2. 祈使句

祈使句中没有主语，表达精炼。在进行理论分析和公式推导中常采用 Assume that...，Suppose that...，Let... 等祈使语气表达方式。

例如：Suppose that $P=0$ at $x=y$. 假设当 $x=y$ 时 $P=0$。

1.3.5 复杂长句使用频繁

为了完整、准确地表达事物的内在联系，使之逻辑严密、结构紧凑，专业文章中往往使用大量从句。理解长句时需要首先厘清句子之间的关系和各个句子的作用，找准主句后依次分析其他修饰成分。例如：

① It has been mentioned above that the electrons in a metal are able to move freely through the metal, that their motion constitutes an electric current in the metal and that they play an important part in conduction of heat. 前面已经提到：金属中电子能自由地通过金属，电子的移动在金属中形成了电流，电子在热传导中起着重要的作用。

该句中采用 It 做形式主语，三个 that 分句并列充当句子的实际主语。

② The testing of a cross-field generator will be described in this section with chief reference to the tests that are normally taken on every machine before it leaves the makers works. 交磁发电机的试验将在本节中叙述，它主要涉及每台发电机在离开制造厂前应进行的试验。

这是一个复合句，主句为：The testing of a cross-field generator（主语）will be described（谓语）。with 引导了一个介词短语做伴随状语，that 引导的定语从句修饰伴随状语中的 tests 一词，before 引导的时间状语从句是上述定语从句的一部分。

③ More particularly, this invention relates to a method and apparatus for forming a film of metal oxides continuously on the surface of ribbon glass by spraying thereon a solution of metal compounds at a point in the neighborhood of the inlet to a lehr or the inside thereof when the ribbon glass is being conveyed to the lehr after it has been formed from molten glass. 更具体地说，本发明涉及在带状玻璃表面上连续地喷涂一层金属氧化膜的一种方法和装置。当玻璃由液态成型为带状玻璃后，在其被送往退火窑时，从退火窑入口附近或入口里将金属化合物溶液喷到玻璃表面上。

这也是一个复合句，较例②结构更为复杂。主句为：this invention（主语）relates to

（谓语）a method and apparatus（宾语）。for 引导了一个介词短语做状语，表达 a method and apparatus 的用途；by 引导的介词短语做状语，表达实现这一用途的方式。在 by 引导的介词短语中，又出现了 when 引导的时间状语从句修饰 spraying 和 after 引出的时间状语从句修饰 is being conveyed。

1.4 修辞特点

1. 时态使用比较单一

就时态而言，由于介绍科技文献所涉及的内容（如科学定义、定理、方程式或公式、图表等）一般没有特定的时间关系，为体现陈述事实的客观性，大部分都使用一般现在时，主要用来介绍客观规律或事实。一般过去时次之，主要用来说明某一具体项目的发展情况，介绍已进行的实验或实验过程。现在完成时应用较少，主要用来介绍论题的发展背景、已完成的工作或取得的成果，在科技报告、科技新闻、科技史料等中常常能看到。过去将来时、完成进行时等时态，在专业英语中很少见。例如：

The machine tools in a workshop sometimes have their own electric motors, or they may take the power they need from a motor which feeds several machines. The shafts which carry the power from the motor to the machines need some kinds of support to keep them steady. We call these supports bearings. There are different types of bearings for different purposes. We can classify them according to where they take the load on the shaft or the thrust along the axis of the shaft. The former type is known as a journal bearing and the latter type as a thrust bearing.

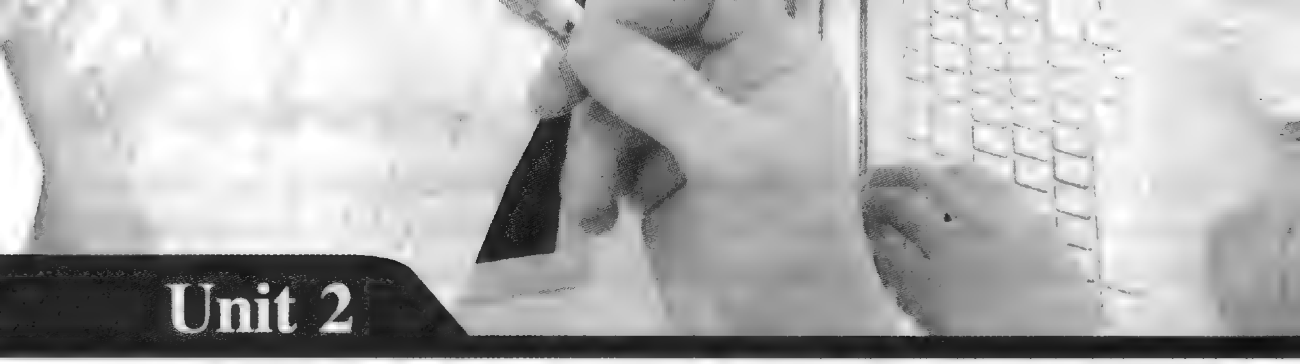
该段共有 6 个句子，全部采用一般现在时介绍客观事实。

2. 较多地使用图、表和公式

专业英语书籍和科技文献中常使用数据、图、表和公式等非语言因素来表明科技概念、原理、定理或定律、规则、方法等，更为直观地辅助说明科学问题。

3. 逻辑语法使用多

为使科学问题论述过程条理清晰、避免歧义，科技文献和专业书籍中进行条件论述、理论分析和公式推导时，多使用逻辑语法，因此会频繁使用表示条件、原因、语气转折、限制、假设和逻辑顺序等词汇，如 although, because, but, if, once, only, suppose, as a result, because of, due to, so, therefore, thus, without 等。



Unit 2

专业英语的理解与翻译

2.1 翻译的基本方式

1. 翻译的定义

语言是人类交流思想的一种手段，使用不同语言的人们要交流思想，必须借助翻译。“翻译”就是一种语言文字的思想内容和风格用另一种语言的习惯表达方式确切而完整地重新表达出来的过程。

2. 翻译的标准

翻译的标准既是衡量译文质量的尺度，也是指导翻译实践的准则，因此翻译的标准一直是翻译工作者关注的问题，其中最有影响的是清末著名的翻译家严复先生在1898年提出的“信、达、雅”三原则。由于这个提法严谨准确，历来为后人所推崇，至今仍有很大影响。只是随着时代的发展，人们对翻译标准的认识，已有了进一步的见解。

机械专业英语属科技英语。就科技英语的翻译而言，其翻译标准有多种说法，有的主张“等值”，有的主张“信、顺”，有的主张“信、达、切”。虽然众说纷纭，但都有一个共同点，即是必须坚持准确、通顺和规范三条标准，即忠实于原文，准确、完整、科学地表达原文内容，使语言通顺连贯，上下文衔接流畅，用词造句符合汉语习惯、符合学科领域规范、符合汉语专业词汇表达的独特语言形式，并且简练紧凑，通俗易懂。

3. 翻译的基本方式及其选择

（1）直译（Literal Translation） 直译是指既忠实于原文的内容，又忠实于原文的形式的翻译方式。英汉两种语言，其句子的主干成分的语序在基本句型中是一致的。这便为直译这种翻译的基本方式奠定了基础。例如：

① All things are difficult before they are easy. 凡事总是由难到易。

② The price of gasoline will come down in Chinese market. 在中国市场汽油的价格会下降。

直译是最为重要的翻译方式，也是所有翻译方式的基础。直译能保证或基本保证译文与原文在形式上的一致，从而具有更忠实于原文的效果，因此翻译时首选直译。但是，直译具有局限性。例如译文有时冗长啰嗦，晦涩难懂，有时不能正确传达原文意义，有时甚至事与愿违。如果不顾场合条件，不顾中外两种历史背景和语言的差异，一味追求直译，就必然造成误译。因此，有时需要意译。

（2）意译（Free Translation/ Paraphrase） 意译是只忠实于原文的内容，不拘泥于原文的形式的一种翻译方式，通常在翻译句子或词组（或更大的意群）时使用较多。意译主要

在原语与译语体现巨大文化差异的情况下得以应用，从跨文化语言交际和文化交流的角度来看，意译强调的是译语文化体系和原语文化体系的相对独立性，因此更能够体现出本民族的语言特征。例如习语、诗词、成语等的翻译，常常通过意译来达到“信、达、雅”。

① Talk of the devil and he will appear. 说曹操，曹操就到。

② Sense comes with age. 老马识途。

(3) 音译 (Transliteration)　音译，就是在译文中按与原文相同的发音造词组句，一般用于外来语的翻译。例如：motor（马达）、radar（雷达）、laser（镭射）、microphone（麦克风）、model（模特）。

(4) 阐译 (Hermeneutic Translation)　阐译是用解释性的语言来表述译文的翻译方式。阐译主要用在两种语言之间没有完全对应事物，但又不能简单用音译来翻译的情况。例如：英语中有 summing settings 一词，汉语中却没有其对应的说法。因此，采用阐译，译成：“指夏季野游时所用的成套物件，包括躺椅、大遮阳伞、野餐工具和游泳蛙掌等。”

翻译毕竟不是解释，翻译是寻找对等，是以译语的对等物表达原语。因此除非不得已，尽量不用阐译。

2.2　典型语法现象的翻译

2.2.1　被动语态

在专业英语中，往往对一种现象的原理阐述和解说比较重视，对于事实的阐述是客观的而非主观臆断，因此被动语态是很常见的。在句子中大量使用被动语态，能在表达客观事实的同时又可以避免读者因猜想而导致的曲解，还能够在句子结构上留出更大的修饰空间，通过采用合适的修辞手段来丰富句子的内容，扩充句子的信息量。

翻译被动语态时，可参考以下方法：

1. 译成汉语的主动式

将英语主语译成汉语宾语，英语中“by 短语”中介词的宾语译为主语，或另加“人们，我们”等为主语，译成汉语的主动式。例如：Radio waves are transmitted by radio stations. 可译为：无线电站传送无线电波。

有时，英语句子的地点状语也可以译成汉语的主语。例如：Multiple threads of 2, 3 and 6 starts can be cut on this machine. 可以译成：这台机器可以加工 2、3 及 6 头的多头螺纹。

2. 译成汉语的无主句

当英语动词的行为主体没有指明，而谓语往往带有状语（尤指行为方式状语）时，可将英语主语译成汉语宾语，译成汉语的无主句。例如：

① Movement is transferred to the spindle via two gears. 通过两个齿轮将运动传递给主轴。

② The control buttons at the switch-board or the two movable pedal-operated switches can be used. 可以使用配电板上的控制按钮或者两个移动式脚踏开关。

3. 直接译成汉语的被动式

也可以直接将英语被动语态译为汉语的被动式。

1) 译为一般被动式：“被” + 及物动词，此时行为主体不出现。例如：

In seeking strength and rigidity, the primary essential of lightweight can never beslighted. 在追求强度和刚度时，任何微小的基本要素都不能被忽略。

2）译为完全被动式：“被”“由”“让”“给”“受到”等字之后跟行为主体加及物动词。例如：

The eight connecting rods are picked up by the transfer bar grippers and moved into the fourth station. 这8个连杆被传送杆夹钳夹住并移动到第四个工位。

3）译成简化被动式：“被”省略的被动式。例如：

When a gas is cooled, the motion of its molecules becomes slower. 当气体冷却后，它的分子的运动就变得缓慢了。

2.2.2 不定式

专业英语要求准确、精炼，而动词的非谓语形式可以很好地实现这些要求。动词不定式作为一种主要的动词非谓语形式，在科技英语中的使用也十分频繁，在句中可以表示目的功能的从句，使句子结构简练。动词不定式及不定式短语的译法需根据它在句中的作用来确定。

1）用作主、表、宾、定语等的动词不定式如带有宾语，可译成汉语的动宾结构，例如：

① Some of the most common methods of imputing information are to use magnetic tape, disk and terminals. 输入信息的一些最普通的方法是使用磁带、磁盘和终端设备。

② The purpose of this catalyst is to accelerate the process of chemical reaction. 这种催化剂的目的是加速化学反应的进程。

③ Voltage, resistance and capacity are the three important properties to influence the flow of current in a circuit. 电压、电阻和电容是影响电路中电流的3个重要因素。

2）用作宾语补足语的动词不定式可连同宾语译成汉语的兼语式。例如：

Then, notice the mixture change its color. 然后，注意混合物改变颜色。

3）有些动词的被动语态，做谓语，如 say, see, hear, know, start, report, announce, believe, suppose, think, expect, assume, declare 等，若动词不定式做主语“补足语”，则应根据汉语的习惯可把英语的主语连同动词不定式译为汉语的主谓结构。例如：

① Uranium is known to possess the highest atomic weight. 人们都知道铀具有最高的原子量。

② Oxygen is known to be colorless. 人们都知道氧气是无色的。

4）表示目的的动词不定式一般位于句首或句尾，可译成汉语的目的状语“为了……”“以便……”等。例如：

① To insure manufacture quality of electrodes, the American Welding Society have set up certain requirements for electrodes. 为了确保电极的制造质量，美国焊接学会已经规定了电极的质量要求。

② We have produced many machines to meet the needs of production. 我们已经生产了很多机器以满足生产的需要。

5）表示结果的动词不定式与 too 或 not enough 连用，可译成“太……不能”，“不

够……不能”。例如：

① Sometimes problems are too complicated to be solved without the aid of computers. 如果没有计算机的辅助，有些问题太过复杂而无法解决。

② The temperature is not high enough to change water into stream. 温度不够高，因而不能将水转化为蒸汽。

6）“for... to...”形式的不定式短语，根据其在句中的作用，可译成相应的主谓结构，for 之后的名词或代词译成主语，动词不定式译成谓语。例如：

It is necessaryfor us to learn advanced science and technology. 我们必须学习先进的科学技术。

2.2.3　分词

为求简洁、精练，我们尽可能用非限定动词、名词化词组及其简化形式来清晰地表达原意。动名词短语可用于取代时间从句或简化时间陈述句；过去分词可以取代被动语态的关系从句；现在分词可以取代主动语态的关系从句。分词短语往往能替代一个从句，避免复杂的主从复合结构，同时省略了动词时态和语态，使句子既不累赘又语意明确。

分词与分词短语在句子中主要做定语、状语或补语，而有“主语”的分词短语则是独立分词短语，翻译时可参考以下方法：

（1）分词或分词短语在句中做定语　此时，需根据其与所说明的词的关系密切程度来确定其译法。

1）单个分词以及与所说明的词的关系甚为密切的分词短语，一般可译成汉语的定语。例如：

① A floating body displaces some water. 漂浮的物体排开一定量的水。

② The described method is widely used in electroplating. 所描述的方法在电镀中广泛使用。

③ The work done by a force is equal to the force times distance. 力做的功等于力的大小乘以作用距离。

2）分词短语若与所说明的词关系不紧密，一般可译成并列关系的分句。

The atom contains a number of electrons revolving around the nucleus. 原子中含有大量的电子，这些电子围绕原子核旋转。

（2）分词短语在句中做状语　此类情况下，分词短语主要表示时间，有时也可表示原因、条件、结果等，翻译时须先弄清分词短语在句中的作用，再译成汉语中相应的状语或分句等。

1）表示时间、原因、条件的分词短语一般在句首，根据其在句中的作用，可译成相应的状语或分句。例如：

① When heated, mercuric oxide decomposes rather readily. 氧化汞受热后非常容易分解。

② Being a good conductor, copper is widely used in industry to conduct electricity. 作为一种良导体，铜被广泛地应用于工业中进行导电。

③ Time permitting, we will get the two experiments finished in one day. 如果时间允许，我们将一天完成两个实验。

2）表示行为方式或伴随情况的分词短语都表示次要的动作，用来说明主要动作，可译

成汉语的行为方式状语或并列谓语。表示伴随情况的独立分词短语，一般位于句尾，可译成汉语的分句。

① The station communicated with the Arctic expedition using short radio-waves. 无线电站利用短波与北极探险队联系。

② Almost all metals are good conductors of electricity, silver being the best of all. 几乎所有的金属都是电的良导体，尤其银的导电性最强。

(3) 做宾语补足语的分词短语可连同宾语译成汉语的兼语式　例如：

It would be necessary to keep the machine-tool running at full speed. 必须使机床全速运行。

2.3 词汇的翻译

2.3.1 增译法

增译法是指出于满足句法结构和修饰效果的需要，在译文中增加一些原文中无其形而有其意的词，从而使译文意义完整和明确的方法。有些英语句子如果略去某些词并不影响全句意思的完整表达，但若在汉语译文中省略，则会产生意义不明确、译文欠通顺等问题；还有一些词在英语惯用法上是意义明确而完整的，但逐词翻译后，却觉得全句意义不够清楚，译文不甚流畅。这两种情况都需要使用增译法来弥补译文的不足。

1. 英语复数名词的增译

翻译英语句中复数名词时，可适当增加表示复数概念的词，如“一些”“许多”“一批”“各种”等词，使其复数意义更加明确。例如：

① A lubricant is any substance which, when inserted between the moving surfaces, can reduce the friction, wear, and heating of machine parts. 任何物质，只要将其置于两个运动表面之间时，能减少摩擦和磨损并使机器零件发热，便可称其为润滑剂。

② Carbon combines with oxygen to form carbon oxides. 碳与氧化合便形成了各种碳化物。

③ The factors, voltage, current and resistance, are related to each other. 电压、电流和电阻这三个因素是相互关联的。

2. 英语中表示动作意义名词的增译

在翻译时常需要根据上下文，在一些表示动作意义的名词后面补充如“作用”“现象”“效应”“方法”“过程”等词。例如：

① These principles will be illustrated by the following transition. 这些原理将用下列演变过程来解释。

② Creep is defined as the gradual extension of a material under a constant applied load. 蠕变是指材料在不变的载荷作用下逐渐伸长的现象。

3. 添加概括性的词引起的增译

例如：These differential equations can be classified as linear or non-linear. 这些微积分方程可以分为线性方程和非线性方程两类。

4. 添加解说性词的增译

英语中借助惯用法或上下文关系省去了不影响全句意思的词语，但汉语译文必须增译这

些省略的词语，否则会使译文文理不通，尤其对某些抽象名词、代词或形容词等译成汉语时必须加上另一名词才能更清楚地表达原文。例如：

① The more complex the casting, the more difficult the alloy and the more difficult the applicable specification, the greater the financial benefit. 铸件结构越复杂，合金越难浇注，铸件使用的技术要求越高，那么经济效益就越大。

② Air pressure decreases with altitude. 气压随海拔高度的增加而下降。

5. 根据修辞连贯的需要，添加语气连贯性词的增译

为了使译文表达通顺，使词与词、句与句之间前后连贯，有时要增加语气连贯性的词，使前后语气加强联系。增加的词主要是连词、介词和副词。例如：

① Many persons learned to program with little understanding of computers and their applications. 虽然许多人对计算机及应用知之甚少，却能够掌握编程的技能。

② White or shining surfaces reflect heat; dark surfaces absorb it. 白色或发亮表面反射热，而暗色表面则吸收热。

6. 被动语态引起的增译

英汉翻译中，很多情况下将英语被动语态翻译为汉语主动式。若原文中没有出现行为主体，有时在译文中增译逻辑主语。被动语态的翻译详见 2. 2. 1 小节。

7. 祈使句引起的增译

英语祈使句具有“命令”“请求”或“叮咛”等含义，因此汉译时应视不同情况添加“请”“要”“应”“须”“试”“千万”“一定”或“务必”等语气词语。例如：

① When the machine is in operation, do keep away from it. 机器运转时，请勿靠近。

② Calculate the unknowns in the following. 试求出下面的未知数。

8. 为再现某些词引起的增译

① 当连词 or 或 and 连接两个修饰成分修饰同一个名词，汉译时往往要再现该名词。例如：We call this field of force the electric or electrostatic field. 这种力场称为电场或静电场。

② 当连词 or 或 and 连接两个谓语动词，汉译时往往要再现该宾语。例如：Changing the number of turns of coils may step up or step down the voltage. 改变线圈匝数可以使电压升高，也可使电压下降。

③ 当连词连接两个或两个以上的名词，由一个形容词修饰，汉译时往往要再现该形容词。例如：The wiring of portable appliances, such as electric fires, icons, or kettles, needs particular care. 便携式电器的布线，如电炉、电熨斗或电热水壶要格外小心。

2.3.2 减译法

减译法并非对原文中的某个不重要的内容省略不翻译，而是因为英语与汉语在句法结构上存在差异，英语句子中需要的词，汉语句子中不一定需要一一翻译出来。有的词在英语中用的非常普遍，但在汉语中却很少使用，甚至根本不用；英语句子中，有的词从语法结构上讲是必不可少的，只是在句子中起单纯的语法作用，并无实际意义；有的词或成分如果按照字面意思一一译出来显得多余、累赘，甚至会造成译文逻辑不通或修辞不当。减译不仅不会影响原文所要表述的内容，反而能使译文更加通顺、严谨、简明扼要。它常用于英语的冠词、代词、介词、连词等。

1. 冠词的减译

英语中冠词是附在普通名词前的一种虚词，本身没有独立的词汇意义，只是对名词起限定和辅助说明的作用。汉语中没有冠词，也没有与之相应的词类。因此在将英语译成汉语时，除少数情况外，冠词一般都应减去不译。例如：

① A liquid metal becomes a gas at or above its boiling point. 在沸点或沸点以上，金属液会变成气态。

② The greater the resistances of a wire, the less electric current will pass through it under the same pressure. 在电压相同的情况下，导线的电阻越大，通过的电流就越小。

但有两种情况例外：

① 当不定冠词具有明显的数字概念或与单数可数名词连用，表示单位数量时，一般必须译出。例如：The vertical element has a fixed part called the vertical stabilizer and a movable part called the rudder. 垂直面上有一个固定的部件，称为垂直尾翼；还有一个可以动的部件，称为方向舵。

② 定冠词在起着特指某具体事物的作用时，通常也必须译出。例如：The ease with which the two surfaces "wet" each other, and the composition of the initial charge and the temperature will determine the carbon solubility in the iron. 这两个表面互相"湿润"的容易程度、初始炉料的化学成分以及温度，将决定碳在铁中的溶解度。

2. 介词的减译

英语中介词丰富，使用频繁。介词常常用来表示名词或代词等和句中其他词之间的关系。汉语中也有介词，但数量有限，使用也不多，词与词之间的关系主要是通过词序和意会来区分。因此在英译汉时，介词除了转译为汉语的其他词类外，减译情况较多。例如：

① In the absence of friction, belts would not be capable of conveying power from one machine to another. 如果没有摩擦，皮带就无法在机器间传递动力。

② Most substance expand in heating and contract on cooling. 大多数物体具有热胀冷缩的特性。

3. 连词的减译

英语在句法构造上采用形合法，所以连词在英语中使用频繁。汉语的句法构造主要采用意合法，故连词用得较少。大多数汉语句子是按时间顺序和逻辑关系排列的，语序固定，各成分之间的关系较清楚。因此在英译汉时，甚至必须将英语中的某些连词减译。

（1）并列连词的减译

① This system is totally enclosed and prevents air pollution from dust particles or gases. 此系统为全封闭式，能防止尘粒或烟气污染大气。

② In general, all the metals are good conductors, with silver the best and copper the second. 通常，所有金属都是良导体，其中银最佳，铜其次。

（2）从属连词的减译

例如：Like charges repel each other while opposite charges attract. 同性电荷相斥，异性电荷相吸。

4. 代词的减译

（1）人称代词的减译

1）在一段文字中，如果紧连的两个句子主语相同，汉语习惯是其中一句可以不用主语。而英语则每句必有主语，常在后一句中用人称代词表示和前句相同的主语。这样使用的英语人称代词往往减译。例如：

① A wire lengthens while it is heated. 金属丝受热则变长。

② The finished products must be sampled to check their quality before they leave the factory. 成品在出厂前必须进行抽样检查。

2）在科技文章中，人称代词中的 we 和 you 往往是泛指，具有“概括”或“不定”的意义，汉译时大多不需译出。例如：

① Given the weight and the specific gravity of a body, we can calculate its volume. 给出物体的重量和密度，就能求出其体积。

② You will see to it that the engine doesn't get out of order. 注意别让发动机出故障。

（2）物主代词的减译　英语中的物主代词一般不能省略。而汉语中在关系已经明确的情况下不必再用物主代词来明确所述关系，因此英译汉时减译英语物主代词的情况十分常见。例如：

① Rivets are permanent fasteners. They depend on deformation of their structure for their holding action. 铆钉是不可拆连接件。它们通过结构变形起固定作用。

② The process of separating a metal from its ore is called smelting. 将金属从矿石中分离出来的过程叫作冶炼。

（3）反身代词的减译　根据汉语的习惯，某些宾语或同位语的反身代词往往可以减译。例如：

① Like zinc, iron also converts itself into a vapor at high temperature. 像锌一样，铁在高温下也会变成气态。

② The gas distributes itself uniformly throughout a container. 气体均匀地分布在整个容器里。

5. 动词的减译

在英语的各类句型中，有一个共同的特点，就是必须有谓语动词，而汉语则不然。除了动词之外，形容词和名词等也可做谓语，因此英译汉时动词有时可以减译。

（1）系动词的减译　某些系动词，如 be，get，become，turn 等后有形容词或各种短语做表语时，该系动词可减译。例如：

① When the pressure gets low, the boiling-point becomes low. 气压低，沸点就低。

② When the design is complete, the system may then be used to produce detailed engineering drawings. 在设计完成时，系统会自动生成详细的工程图。

（2）行为动词的减译　有时，行为动词也可以减译。例如：

① Hence, television signals have a short range. 因此，电视信号范围有限。

② Then came the development of the microcomputer. 后来，微型计算机发展了起来。

6. 同义词或近义词的减译

在表达概念时，常有两个同义词连用的现象，即对同一个概念用两个词重复表达。作者这样做往往是处于强调或为了适应同层次的读者的需要。前一个词是专业词汇，后一个词是普通词汇。两者在语法上是同位关系，常可用连词“or”连接。但在汉译时，为了使概念准

确，避免文字重复或含糊不清，只需要译出其中一个汉语中通用的名称。

例如：The force of gravity acts vertically downwards and gives an object "weight" or "heaviness". 重力垂直向下作用，使物体具有“重量”。

2.3.3 词义引申

英汉两种语言在表达方式上差别很大。翻译时，有些词或词组无法直接搬用辞典中的释义，若勉强按辞典中的释义逐词死译，会使译文生硬晦涩、很难看懂，甚至会造成误解。所以，要在弄清原文词义的基础上，根据上下文的逻辑关系和汉语的搭配习惯，对词义加以引申。

词义的引申是指在一个词所具有的原始意义的基础上，根据上下文和逻辑关系进一步加以引申，选择适当确切的目标语词语来表达，避免生搬硬套地逐句死译，使译文更加通顺流畅。值得注意的是，词义的引申不得超出原始意义所允许的范围。

1. 词义转译

遇到一些无法直译的词或词组时，应根据上下文和原词的字面意思做适当的转化。例如：

① Like any precision device, the monitor of methane requires careful treatment. 跟任何精密仪器一样，瓦斯监测仪也需要精心维护。

② There is no physical contact between tools and workpieces. 工具和工件不直接接触。

③ High-speed grinding does not know this disadvantage. 高速磨床不存在这个缺点。

2. 词义的具体化

英语中常用代表抽象意义的词表示一种具体事物，译成汉语时一般需做具体的引申，否则意义会不明朗。因此，翻译时应根据汉语的表达习惯，把文中抽象笼统的词语引申为意义明确、具体的词语。例如：

① The purpose of a driller is to holes. 钻机的功能是钻孔。

② A single-point cutting tool is used to cut threads on engine lathes. 卧式车床是用单刃刀具来车螺纹的。

③ Other things being equal, iron heats up faster than aluminum. 其他条件相同时，铁比铝热得快。

3. 词义的抽象化

翻译时，把原文中词义较具体的词引申为词义较抽象的词，或把词义较形象的词引申为词义较一般的词。例如：

① The major contributors in component technology have been the semi-conductor components. 元件技术中起主要作用的是半导体元件。

② Steel and cast iron also differ in carbon. 钢和铸铁的含碳量也不相同。

③ We have progressed a long way from the early days of electrical engineering. 电气工程自从出现以来，已经有了很大的发展。

2.3.4 词性转换

由于英汉两种语言属于不同的语系，所以它们在语言结构与表达形式方面各有特点。要

使译文既忠实于原文，又顺畅可读，就不能局限于逐词对等，必须采用适当的词性转换。

1. 转译成汉语动词

（1）名词转译成动词

A change of state from a solid to a liquid form requires heat energy. 从固态变为液态需要热能。

（2）介词转译成动词

In any machine input work equals output work plus work done against friction. 任何机器的输入功，都等于输出功加上克服摩擦所做的功。

（3）形容词转译成动词

① Both of the substances are not soluble in water. 这两种物质都不溶于水。

② In this case the temperature in furnace is up. 在这种情况下，炉温就升高。

2. 转译成汉语名词

某些表示事物特征的形容词做表语时，可将其转译成名词，其后往往加上“性”“度”“体”等。带有定冠词的某些形容词用作名词，应译成名词。副词有时也可转译为名词。

（1）形容词转译成名词

① The cutting tool must be strong, tough, hard, and wear resistant. 刀具必须具有足够的强度、韧性、硬度和耐磨性。

② Both the compounds are acids, the former is strong, the latter is weak. 这两种化合物都是酸，前者是强酸，后者是弱酸。

（2）副词转译成名词

All structural materials behave plastically above their elastic range. 超过弹性极限时，一切结构材料都会显示出塑性。

3. 转译成汉语形容词

（1）名词转译成形容词

This experiment was asuccess. 这个试验是成功的。

（2）副词转译成形容词

① This man-machine system is chiefly characterized by its simplicity of operation and the ease with which it can be maintained. 这种人机系统的主要特点是操作简单，容易维修。

② The equations below are derived from those above. 下面的方程式是由上面的那些方程式推导出来的。

4. 转译成汉语副词

形容词转译成副词

① The mechanical automatization makes for a tremendous rise in labor productivity. 机械自动化可以大大地提高劳动生产率。

② In case of use without conditioning the electrode, frequent calibrations are required. 如果在使用前没有调节电极，则需要经常校定。

③ A continuous increase in the temperature of the gas confined in a container will lead to a continuous increase in the internal pressure within the gas. 不断提高密封容器内气体的温度，会使气体的内压力不断增大。

2.4 句子的翻译

2.4.1 定语从句

定语从句是英语后置定语的一种，在英语中使用定语从句能使科技内容的描述更加严密、准确，但也使科技英语文章中的句子更加复杂。因此，翻译定语从句时要在准确传达原文意思的同时，尽量保证汉语表达的通顺，避免过分受原文结构的束缚而难以理解。可根据不同情况灵活选用合译法、分译法和转译法等方法来翻译定语从句。

1. 合译法

（1）结构简单的定语从句　结构简单的定语从句，无论是限制性定语从句还是非限制性定语从句，可根据上下文，用“……的”句型将从句译成前置定语，从而将复合句译成汉语单句。例如：

① The cam is driven by a known input motion, usually a shaft which rotates at constant speed, and it is intended to produce a certain desired output motion for the follower. 凸轮由一个已知的输入运动驱动，通常由一个等速转动的轴驱动，使从动件产生预期的输出运动。

② The rate at which work is done is called power. 做功的速率称为功率。

③ The melting point of steel whose carbon content is higher is lower. 含碳量较高的钢熔点较低。

（2）There + be 句型中的限制性定语从句　英译汉时往往可以把主句中的主语和定语从句融合在一起，译成一个独立的句子。这种译法叫作融合法，也叫拆译法。例如：

There are bacteria that help plants grow, others that get rid of dead animals and plants by making them decay, and some that live in soil and make it better for growing crops. 有些细菌能帮助植物生长，另一些细菌则通过腐蚀来消除死去的动物和植物，还有一些细菌则生活在土壤里，使土壤变得对种植庄稼更有好处。

（3）以 as 引导的限制性定语从句　关系代词 as 经常与 such, the same, as many, as such 等配合使用。在这些句型中 as 引导限制定语从句。以 as 引导的这类限制性定语从句往往有比较固定的一些译法。

1）such +（名词）+ as 或 such as，通常译为“像……之类的”“像……那样的”“……的一种”等。

例如：Such liquid fuel rockets as are now being used for space research have to carry their own supply of oxygen. 目前像这类应用于宇宙研究的液态燃料火箭，通常必须自带氧气。

2）the same... as，通常译为“和……一样的”“与……相同的”。

例如：A color transmission contains the same information as a black and white transmission. 彩色传输所容纳的信息和黑白传输容纳的信息相同。

2. 分译法

非限制性定语从句，用来说明整个句子的特种定语从句以及较长的限制性定语从句，一般都可以译为并列分句或独立句。如果第二个分句的主语是重复关系代词所替代的名词，还可在该名词前加“该”“它们”“这”或“后者”等。如果是用来说明整个句子的特种定语

从句，通常用“这”字代替第一个分句的整个概念，把它作为第二个分句的主语。例如：

① Some 200 years ago, an unknown engineer invented the Oldham coupling, which allows two parallel but misaligned shafts to be efficiently coupled. 大约200年前，一个不知名的工程师发明了 Oldham 联轴器。这种联轴器能把两个互相平行但又未对中的轴有效地连接起来。

② An object in water experiences a buoyant force which is equal to the weight of the displaced water. 物体在水中受到浮力的作用，该力等于所排出水的重量。

3. 转译法

英语的定语从句和主语之间的关系较为复杂，有时仅从语法结构上分析从句和先行词的关系十分费解。这是由于有一些定语从句（包括限制性和非限制性定语从句）对先行词的修饰作用已经十分有限，仅相当于状语的作用，表达原因、条件、结果、让步、目的、时间等。因此，翻译定语从句时应仔细理顺主从句之间的逻辑关系，把具有状语功能的定语从句转译为合适的状语从句。

（1）译成原因分句

① A solid fuel, like coal or wood, can only burn at the surface, where it comes into contact with the air. 像煤和木材这样的固体燃料，燃烧只发生在表面，因为只有表面与空气接触。

② Copper, whose resistance is low, can serve as a good conductor。铜因为电阻小，所以是一种良导体。

（2）译成结果分句

① Matter has certain features or properties that enable us to recognize it easily. 任何物质都有特定的特性，易于辨认。

② Copper, which is used widely for carrying electricity, offer very little resistance.

铜的电阻很小，所以广泛用于传送电力。

（3）译成让步分句

① The factory, which is small, produces a large quantity of machines every day.

工厂虽小，每天却可生产大量机器。

② Electronic computers, which have many advantages, cannot carry out creative work and replace man.

尽管电子计算机有许多优点，但它们无法进行创造性的工作，因此无法代替人类。

（4）译成目的分句

① The bulb is sometimes filled with an inert gas which permits operation at a higher temperature. 有时在灯泡内充入惰性气体，为了使其能在相对高温条件下工作。

② An improved design of such a large tower must be achieved which results in more uniformed temperature distribution in it. 为了使塔内温度分布更为均匀，必须对这种大型塔的设计改进。

（5）译成条件分句

① For any machine whose input force and output force are known, its mechanical advantage can be calculated. 对于任何机器，只要其输入力和输出力已知，便能求出其机械效益。

② Substance that contain only atoms with same properties are called elements. 如果物质仅包含相同性质的原子，便称之为元素。

（6）译为时间分句

① Electrical energy that is supplied to a lamp can be turned into light energy. 给电灯通电时，电能就能变成光能。

② Electricity which is passed through the thin tungsten wire inside the bulb makes the wire very hot. 当电流通过灯泡里的钨丝，钨丝会达到较高的温度。

2.4.2 长句

英语习惯于用长句表达复杂的概念，而汉语则习惯使用若干短句按主次顺序层次分明地进行阐述，这种差别对于英译汉工作是一个极大的挑战。要译好英语中的长句，首先必须厘清原文的句法结构，抓住全句的中心内容，弄清句子各层次之间的逻辑关系，然后用流畅、简洁的汉语准确地译出原文的意思，不必拘泥于原文的形式。因此，找到一些对策是非常必要的。

英语长句的译法一般可分为四种：拆分法、顺序法、逆序法和主次分译法。

1. 拆分法

拆分法即将较长英语句子划分为几个独立句或并列的分句，这是理解长句的一种常见而又有效的对策。例如：

① The procedures are chamfering both sides of the gudgeon pin and crank pin core and semi-finishing the crank pin bore at a rate of 1000 pieces per hour at 100% efficiency. 加工工序是对活塞销孔和曲轴销孔的两侧端面倒角，并对曲轴销孔进行半精镗加工，在负荷率 100% 时，生产率为每小时 1000 件。

分析：从介词 at 处断开译成两句，后句补充前句，正确地表达了原意。

② Then he closes a safety gate, depresses a pair of pushbuttons, and the loader swings the eight (linking) rods up 90°. Into station No. 1, where they are trapped and picked up by grippers on the upper and lower transfer bars. 然后他关上安全挡板，压下一对按钮，自动上料装置进行摆动，将 8 个连杆转动 90°后送到第一工位上，上下输送杆的夹爪在那里把连杆抓起。

分析：从 and the loader 和 where 处断开，译成三句。前后层次清楚，句意分明。

2. 顺序法

英语长句的叙述层次基本上与汉语相同时，可以按英语的顺序，依次译出。例如：

① In factories and all other places where radioactive materials are used, great care must be taken to prevent anyone from being injured by coming too close to a strong radioactive source or by breathing the radioactive dust, for the rays form radioactive substances can be very dangerous. 在使用放射性物质的工厂和其他所有地方，必须特别小心，防止任何人由于靠近强烈的放射源或由于吸进了放射性微尘而受到伤害，因为来自放射性物质的射线是非常危险的。

② A broaching line which produces a completely broached (linking) rod and cap every 12 seconds comprises two linked standard Cincinnati chain broachers, one a 30 by 114 and the other a 30 by 120 machine, with specially designed automatic loaders, locating devices and work transfer equipment. 拉削自动线每隔 12 秒钟完成一副连杆体和连杆帽的全部拉削工序，由两台辛辛那提普通链式拉床连接而成。一台是 30 × 114，另一台是 30 × 120。自动线上备有专用的自动上料、定位和工件输送装置。

3. 逆序法

英语长句叙述层次与汉语的习惯表达层次相反时，需要颠倒英语的次序，从后向前地译出。例如：

Trouble shooting of this instrument is easily effected by checking the voltage, wave form and so on through the check terminals as explained in the section pertaining to maintenance. 正如有关维修的那节所阐述的那样，通过检查接头来检查电压、波形等参数，就容易检查出这种仪器的故障。

4. 主次分译法

英语长句中一些修饰成分，如分词短语、介词短语、从句等，与被修饰词的关系并不密切时，可先把句子的主要部分译出，然后再阐述次要部分，使译文主次分明，层次清楚。例如：

① An atom consists primarily of one or more electrons orbiting around one or more protons in the center, or the nucleus. 原子主要是由一个或一个以上的电子和一个或一个以上的质子所组成，质子位于原子的中心，即原子核内，电子则围绕质子旋转。

② Manufacturing processes may be classified as unit production with small quantities being made and mass production with large numbers of identical parts being produced. 生产过程可分为单件生产和批量生产：单件生产就是生产少量的工件，批量生产就是生产大量规格相同的工件。

2.4.3 否定句

1. 部分否定

在英语的否定结构中，由于习惯用法问题，其中部分否定句所表示的意思是不能按字面顺序译成汉语的，因此，翻译时要特别注意。英语中含有全体意义的代词和副词如 all, every, both, always, altogether, entirely 等统称为总括词，它们用于否定结构时不是表示全部否定，而只表示其中的一部分被否定。因此，汉译时不能译作“一切……都不”，而应译为“并非一切……都是的”，或“一切……不都是”。例如：

① All of the heat supplied to the engine is not converted into useful work.

正确：并非供给热机的所有热量都被转变为有用功。

错译：所有供给热机的热量都没有被转变为有用功。

② Every one cannot do these tests.

正确：并非人人都能做这些试验。

错译：每个人都不能做这些试验。

③ Both instruments are not precise.

正确：两台仪器并不都是精密的。

错译：两台仪器都不是精密的。

④ This plant does not always make such machine tools.

正确：这个工厂并不总是制造这样的机床。

错译：这个工厂总是不制造这样的机床。

2. 全部否定

当总括词 + 肯定式谓语 + 含否定意义的单词……）时，则是表示全部否。例如：

① All germs are invisible to the naked eye. 一切细菌都是肉眼看不见的。

② Every design made by her is impossible of execution. 她所做的一切设计都是不能执行的。

③ Both data are incomplete. 两个数据都不完整。

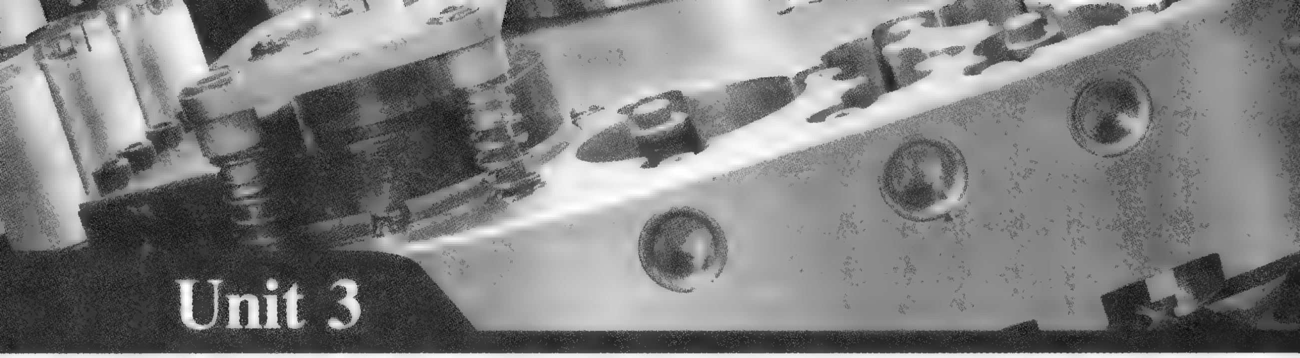
④ In practice, error sometimes always seems unavoidable. 在实践中，差错有时似乎总是不可避免的。

Reading and Comprehension

Part 2 阅读理解

本部分为本书设置的第一个专业英语实践环节——阅读理解，文字摘自多部原版英文著作，内容全面，涉及机械制图、力学基础、机器设计、零件设计、工程材料、制造技术及机器人等方面的专业知识。书中还对疑难句子进行了释疑，并且提供了主要专业词汇的释义。

本部分的学习侧重培养阅读和翻译能力。通过学习，学生应掌握较为全面、重要的专业词汇，在不断的阅读中体会专业英语与普通英语文体的区别，了解专业英语的特点，最重要的是要结合 Unit 2 所学的方法锻炼专业英语的阅读能力，提升理解翻译的准确度。



Unit 3

An Overview of Mechanical Engineering

3.1 Engineering and Main Branches

3.1.1 Definition of Engineering

Engineering is the practical and creative application of science and mathematics to solve problems, and it is found in the world all around us. Engineering technologies improve the ways that we safely travel, work, communicate and even stay healthy. One who practices engineering is called an engineer. Engineers are the innovators, planners, and problem-solvers of our society. They are always seeking quicker, better, and less expensive ways to benefit mankind. In that sense, the work of an engineer differs from that of a scientist, who would normally emphasize the fundamental discovery of physical laws rather than their application to product development. Engineering serves as the bridge between scientific discovery, commercial application, and business marketing.

3.1.2 Main Branches of Engineering

Engineering, much like other science, is a broad discipline which is often broken down into several subdisciplines. The broad discipline of engineering encompasses a range of more specialized subdisciplines, each with a more specific emphasis on certain fields of application and particular areas of technology. These disciplines concern themselves with differing areas of engineering work. Although initially an engineer will usually be trained in a specific discipline, throughout an engineer's career the engineer may become multi-disciplined, and have worked in several of the outlined areas. Engineering is often characterized as having five main branches.

(1) Chemical engineering. The application of physics, chemistry, biology, and engineering principles in order to carry out chemical processes on a commercial scale.

(2) Civil engineering. The design and construction of public and private works, such as infrastructure (airports, roads, railways, water supply and treatment, etc.), bridges, dams, and buildings.

(3) Electrical engineering. The design and study of various electrical and electronic systems,

such as electrical circuits, generators, motors, electromagnetic/electro-mechanical devices, electronic devices, electronic circuits, optical fibers, opto-electronic devices, computer systems, telecommunications, instrumentation, controls, and electronics.

(4) Material engineering. The study of the properties of solid materials and how those properties are determined by the material's composition and structure, both macro-scopic and microscopic. With a basic understanding of the origins of properties, materials can be selected or designed for an enormous variety of applications, from structural steels to computer microchips. Materials science is therefore important to many engineering fields, including electronics, aerospace, telecommunications, information processing, nuclear power, and energy conversion.

(5) Mechanical engineering. The design of physical or mechanical systems, such as power and energy systems, aerospace/aircraft products, weapon systems, transportation products' engines, compressors, power trains, kinematic chains, vacuum technology, and vibration isolation equipment.

(From *English Communication for Mechanical Engineers* by L. Kang)

3.2 Mechanical Engineering and Fundamentals

Mechanical engineering is the branch of engineering that deals with machines and the production of power, applying the principles of physics and materials science for analysis, design, manufacturing, and maintenance of mechanical systems. It is particularly concerned with forces and motion.

3.2.1 History of Mechanical Engineering

The invention of the steam engine in the latter part of the 18th century, providing a key source of power for the Industrial Revolution, gave an enormous impetus to the development of machinery of all types. As a result a new major classification of engineering, separate from civil engineering and dealing with tools and machines, developed, receiving formal recognition in 1847 in the founding of the Institution of Mechanical Engineers in Birmingham, England.

Mechanical engineering has evolved from the practice by the mechanic of an art based largely on trial and error to the application by the professional engineer of the scientific method in research, design, and production.

The demand for increased efficiency, in the widest sense, is continually raising the quality of work expected from a mechanical engineer and requiring of him a higher degree of education and training. Not only must machines run more economically but capital costs also must be minimized.

3.2.2 Fields of Mechanical Engineering

1. Machines for the Production of Goods

The high material standard of living in the developed countries owes much to the machinery made possible by mechanical engineering. The mechanical engineer continually invents machines to

produce goods and develops machine tools of increasing accuracy and complexity to build the machines.

The principal lines of development of machinery have been an increase in the speed of operation to obtain high rates of production, improvement in accuracy to obtain quality and economy in the product, and minimization of operating costs. These three requirements have led to the evolution of complex control systems.

The most successful production machinery is that in which the mechanical design of the machine is closely integrated with the control system, whether the latter is mechanical or electrical in nature . A modern transfer line (conveyor) for the manufacture of automobile engines is a good example of the mechanization of a complex series of manufacturing processes. Developments are in hand to automate production machinery further, using computers to store and process the vast amount of data required for manufacturing a variety of components with a small number of versatile machine tools. One aim is a completely automated machine shop for batch production, operating on a three-shift basis but attended by a staff for only one shift per day.

2. Machines for the Production of Power

Production machinery presupposes an ample supply of power. The steam engine provided the first practical means of generating power from heat to augment the old sources of power from muscle, wind, and water. One of the first challenges to the new profession of mechanical engineering was to increase thermal efficiencies and power. This was done principally by the development of the steam turbine and associated large steam boilers. The 20th century has witnessed a continued rapid growth in the power output of turbines for driving electric generators, together with a steady increase in thermal efficiency and reduction in capital cost per kilowatt of large power stations. Finally, mechanical engineers acquired the resource of nuclear energy, whose application has demanded an exceptional standard of reliability and safety involving the solution of entirely new problems. The control systems of large power plants and complete nuclear power stations have become highly sophisticated networks of electronic, fluidic, electric, hydraulic, and mechanical components, all of these involving the province of the mechanical engineer.

The mechanical engineer is also responsible for the much smaller internal combustion engines, both reciprocating (gasoline and diesel) and rotary (gas-turbine and Wankel) engines, with their widespread transport applications. In the transportation field generally, in air and space as well as on land and sea, the mechanical engineer has created the equipment and the power plant, collaborating increasingly with the electrical engineer, especially in the development of suitable control system.

3. Millitary Weapons

The skills applied to war by the mechanical engineer are similar to those required in civilian applications, though the purpose is to enhance destructive power rather than to raise creative efficiency. The demands of war have channeled huge resources into technical fields, however, and led to developments that have profound benefits in peace. Jet aircraft and nuclear reactors are notable examples.

4. Bioengineering

Bioengineering is a relatively new and distinct field of mechanical engineering that includes the provision of machines to replace or augment the functions of the human body and of equipment for use in medical treatment. Artificial limbs have been developed incorporating such lifelike functions as powered motion and touch feedback. Development is rapid in the direction of artificial spare-part surgery. Sophisticated heart-lung machines and similar equipment permit operations of increasing complexity and permit the vital functions in seriously injured or diseased patients to be maintained.

5. Environmental Control

Some of the earliest efforts of mechanical engineers were aimed at controlling man's environment by pumping water to drain or irrigate land and by ventilating mines. The ubiquitous refrigerating and air-conditioning plants of the modern age are based on a reversed heat engine, where the supply of power "pumps" heat from the cold region to the warmer exterior.

Many of the products of mechanical engineering, together with technological developments in other fields, have side effects on the environment and give rise to noise, pollution of water and air, and the dereliction of land and scenery. The rate of production, both of goods and power, is rising so rapidly that regeneration by natural forces can no longer keep pace. A rapidly growing field for mechanical engineers and others is environmental control, comprising the development of machines and processes that will produce fewer pollutants and of new equipment and techniques that can reduce or remove the pollution already generated.

3. 2. 3 Functions of Mechanical Engineering

Four functions of the mechanical engineering, common to all the fields mentioned, will be cited . The first is the understanding of and dealing with the bases of mechanical science. These include dynamics, concerning the relation between forces and motion, such as in vibration; automatic control; thermodynamics, dealing with the relations among the various forms of heat, energy, and power; fluid flow; heat transfer; lubrication; and properties of materials.

Second is the sequence of research, design, and development. This function attemptsto bring about the changes necessary to meet present and future needs. Such work requires not only a clear understanding of mechanical science and an ability to analyze a complex system into its basic factors, but also the originality to synthesize and invent.

Third is production of products and power, which embraces planning, operation, and maintenance. The goal is to produce the maximum value with the minimum investment cost while maintaining or enhancing longer term viability and reputation of the enterprise or the institution.

Fourth is the coordinating function of the mechanical engineering, including management, consulting, and, in some cases, marketing.

In all of these functions there is a long continuing trend toward the use of scientific of traditional or intuitive methods, an aspect of the ever-growing professionalism of mechanical engineering. Operations research, value engineering, and PABLA (problem analysis by logical approach) are typical titles of such new rationalized approaches. Creativity, however, cannot be rationalized. The ability to take the

important and unexpected step that opens up new solutions remains in mechanical engineering, as elsewhere, largely a personal and spontaneous characteristic.

3.2.4 The Future of Mechanical Engineering

The number of mechanical engineers continues to grow as rapidly as ever, while the duration and quality of their training increases. There is a growing awareness, however, among engineers and in the community at large that the exponential increase in population and living standards is raising formidable problems in pollution of the environment and the exhaustion of natural resources; this clearly heightens the need for all of the technical professions to consider the long-term social effects of discoveries and developments. There will be an increasing demand for mechanical engineering skills to provide for man's needs while reducing to a minimum the consumption of scarce raw materials and maintaining a satisfactory environment.

(From *Encyclopedia Britannica* by J. F. Br. and P. McG. R.)

3.3 Essential Qualities of Good Engineers

Although the activities of engineers are quite varied, there are some personality traits and work habits that typify most of today's successful engineers. The following is common traits of good engineers:

1) Engineers are problem solvers.

2) Good engineers have a firm grasp of the fundamental principles of engineering, which they can use to solve many different problems.

3) Good engineers are analytical, detailed-oriented, and creative.

4) Good engineers have a desire to be lifelong learners. For example, they take continuing education classes, seminars, and workshops to stay abreast of innovations and new technologies. This is particularly important in today's world because the rapid changes in technology will require you as an engineer to keep pace with new technologies. Moreover, you will risk being laid off or denied promotion if you are not continually improving your engineering education.

5) Good engineers, regardless of their area of specialization, have a core knowledge that can be applied to many areas. Therefore, well-trained engineers are able to work outside their area of specification in other related fields. For example, a good mechanical engineer with a well-rounded knowledge base can work as an automotive engineer, an aerospace engineer, or as a chemical engineer.

6) Good engineers have written and oral communication skills that equip them to work well with colleagues and to convey their expertise to a wide range of clients.

7) Good engineers have time-management skills that enable them to work productively and efficiently.

8) Good engineers have good "people skills" that allow them to interact and communicate effectively with various people in their organization. For example, they are able to communicate

equally well with the sales and marketing experts and their own colleagues.

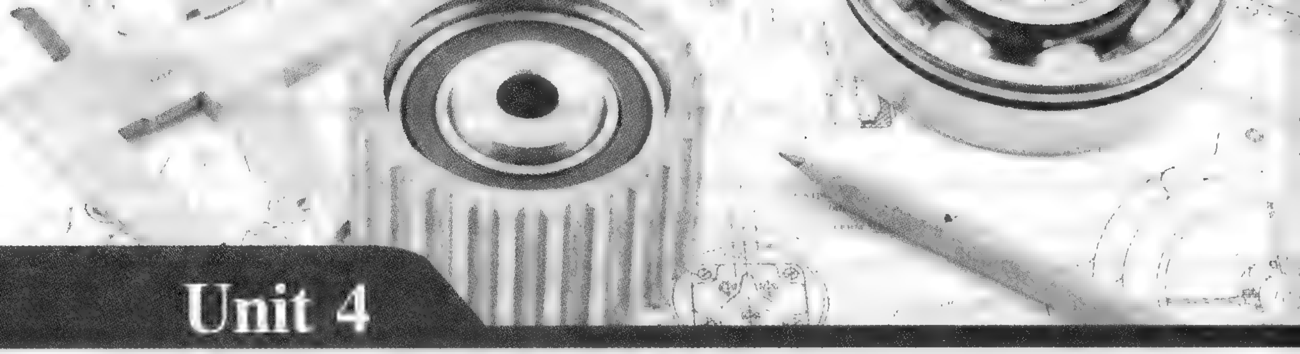
9) Engineers are required to write reports. These reports might be lengthy, detailed technical reports containing graphs, charts, and engineering drawings, or they may take the form of brief memoranda or executive summaries.

10) Engineers are adept at using computers in many different ways to model and analyze various practical problems.

11) Good engineers actively participate in local and national discipline-specific organizations by attending seminars, workshops and meetings. Many even make presentations at professional meetings.

12) Engineers generally work in a team environment where they consult each other to solve complex problems. They divide up the task into smaller, manageable problems among themselves; consequently, productive engineers must be good team players. Good interpersonal and communication skills are increasingly important now because of the global market. For example, various parts of a car could be made by different companies located in different countries. In order to ensure that all components fit and work well together, cooperation and coordination are essential, which demands strong cross-culture communication skills.

(From *English Communication for Mechanical Engineers* by L. Kang)



Unit 4

Mechanical Drawing

4.1 Engineering Drawing

Engineering drawing is a graphical language used by engineers and other technical personnel associated with the engineering profession. The purpose of engineering drawing is to convey graphically the ideas and information necessary for the construction or analysis of machines, structures, or systems. In colleges and universities, engineering drawing is usually treated in courses with titles like Engineering Graphics. Sometimes these courses include other topics, such as computer graphics and nomography.

The basis for much engineering drawing is orthographic representation (projection). Objects are depicted by front, top, side, auxiliary, or oblique views, or combinations of these. The complexity of an object determines the number of views shown. At times, pictorial views are also shown.

Engineering drawings often include such features as various types of lines, dimensions, lettered notes, sectional views and symbols. They may be in the form of carefully planned and checked mechanical drawings, or they may be freehand sketches. Usually a sketch precedes the mechanical drawing. Final drawings are usually made on paper, cloth or mylar film, so that many copies can be made quickly and cheaply by such processes as, blueprinting, ammonia-developed (diazo) printing, or lithography.

1. Section Drawings

Many objects have complicated interior detail which cannot be clearly shown by means of front, top, side, or pictorial views. Section views enable the engineer or detailer to show the interior detail in such cases. Features of section drawings are cutting-plane symbols, which show where imaginary cutting planes are passed to produce the sections, and section-lining (sometimes called cross-hatching), which appears in the section view on all portions that have been in contact with the cutting plane. When only a part of the object is to be shown in section, conventional representation such as a revolved, rotated, or broken-out section is used. Details such as flat surfaces, knurls, and threads are treated conventionally, which facilitates the making and reading of engineering drawings by experienced personnel. Thus, certain engineering drawings will be combinations of top and front views, section and rotated views, and partial or pictorial views.

2. Dimensioning

In addition to describing the shape of objects, many drawings must show dimensions, so that workers can build the structure or fabricate parts that will fit together. This is accomplished by placing the required values along dimension lines (usually outside the outlines of the object) and by giving additional information in the form of notes which are referenced to the parts in question by angled lines called leaders. In drawings of large structures the major unit is the foot, and in drawings of small objects the unit is the inch. In metric dimensioning, the basic unit may be the meter, the centimeter, or the millimeter, depending upon the size of the object or structure.

Working types of drawings may differ in styles of dimensioning, lettering (inclined lowercase, vertical uppercase, and so on), positioning of the numbers (aligned, or unidirectional—a style in which all numbers are lettered horizontally), and in the type of fraction used (common fractions or decimal fractions). If special precision is required, an upper and a lower allowable limit are shown. Such tolerance, or limit, dimensioning is necessary for the manufacture of interchangeable mating parts, but unnecessarily close tolerances are very expensive.

3. Layout Drawings

Layout drawings of different types are used in different manufacturing fields for various purposes. One is the plant layout drawing, in which the outline of the building, work areas, aisles, and individual items of equipment are all drawn to scale. Another type is the aircraft, or master, layout, which is drawn on glass cloth or on steel or aluminum sheets. The object is drawn to full size with extreme accuracy. The completed drawing is photographed with great precision, and a glass negative made. From this negative, photo templates are made on photosensitized metal in various sizes and for different purposes, thereby eliminating the need for many conventional detail drawings. Another type of layout, or preliminary assembly, drawing is the design layout, which establishes the position and clearance of parts of an assembly.

4. Assembly Drawings

A set of working drawings usually includes detail drawings of all parts and an assembly drawing of the complete unit. Assembly drawings vary somewhat in character according to their use, as: design assemblies or layouts; working drawing assemblies; general assemblies; installation assemblies; and check assemblies. A typical general assembly may include judicious use of sectioning and identification of each part with a numbered balloon. Accompanying such a drawing is a parts list, in which each part is listed by number and briefly described; the number of pieces required is stated and other pertinent information given. Parts lists are best placed on separate sheets and typewritten to avoid time-consuming and costly hand lettering.

5. Schematic Drawings

Schematic or diagrammatic drawings make use of standard symbols and single lines between symbols which indicate the direction of flow. In piping and electrical schematic diagrams, symbols recommended by the American National Standards Institute (ANSI), other agencies, or the Department of Defense (DOD) are used. The fixtures or components are not labeled in most schematics because readers usually know what the symbols represent.

Additional information is often lettered on schematic drawing, for example, the identification of each replaceable electrical component. Etched-circuit drawing has revolutionized the wiring of electronic components. By means of such drawing, the wiring of an electronic circuit is photographed on a copper-clad board, and unwanted areas are etched away. On electrical and other types of flow diagrams, all single lines (often with arrows showing direction of flow) are drawn horizontally or vertically; there are few exceptions. In some flow diagrams, rectangular enclosures are used for all items. Lettering is usually placed within the enclosures.

6. Structural Drawings

Structural drawings include design and working drawings for structures such as buildings, bridges, dams, tanks, and highways. Such drawings form the basis of legal contracts. Structural drawings embody the same principles as do other engineering drawings, but use terminology and dimensioning techniques different from those shown in previous illustrations.

(From *McGraw-Hill Encyclopedia of Engineering* by C. J. Baer)

4.2 Views

4.2.1 The Orthographic Projection

The orthographic projection shows the object as it looks from the front, right, left, top, bottom, or back, and are typically positioned relative to each other according to the rules of either first-angle or third-angle projection. The origin and vector direction of the projectors (also called projection lines) differs, as explained in Figure 4-1.

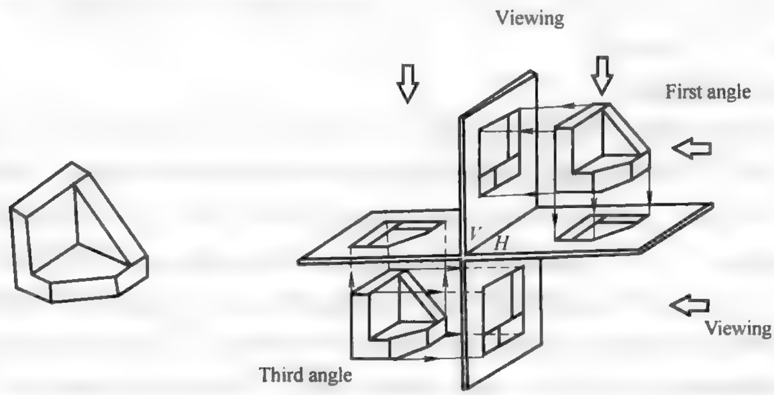
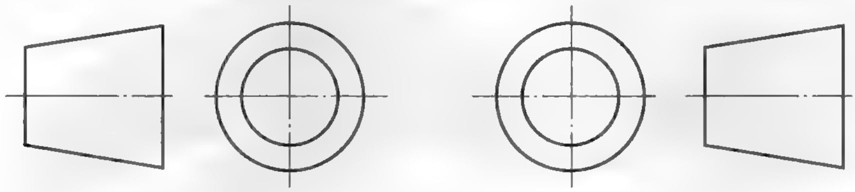


Figure 4-1 First-angle projection and third-angle projection

In first-angle projection, the projectors originate as if radiated from a viewers eyeballs and shoot through the 3D object to project a 2D image onto the plane behind it. The 3D object is projected into 2D "paper" space as if you were looking at a radiograph of the object: the top view is under the front view; the right view is at the left of the front view. First-angle projection is the ISO standard and is primarily used in China and Europe.

In third-angle projection, the projectors originate as if radiated from the 3D object itself and shoot away from the 3D object to project a 2D image onto the plane in front of it. The views of the 3D object are like the panels of a box that envelopes the object and the panels pivot as they open up flat into the plane of the drawing. Thus the left view is placed on the left and the top view on the top; and the features closest to the front of the 3D object will appear closest to the front view in the drawing. Third-angle projection is primarily used in the United States and Canada, where it is the default projection system according to British Standard BS 8888 and ASME standard ASME Y14. 3M.

To ensure that those reading the drawing know whether it is first-angle projection or third-angle projection, use one of two symbols illustrated in the title block, as shown in Figure 4-2.



a) b)

Figure 4-2 Projection symbols

a) First-angle projection symbol b) Third-angle projection symbol

4. 2. 2 Multiple Views

Six principle views: Here let's assume an object is placed inside of an imaginary transparent box, then project the object onto six planes respectively based on the orthographic projection, and thus six principle views are obtained, they are front, back, top, bottom, right side, left side views, as shown in Figure 4-3.

Not all views are necessary to illustrate an object. Generally only as many views are used as are necessary to convey all needed information clearly and economically. The front, top, and right side views are commonly considered the core group of views included by default, but any combination of views may be used depending on the needs of the particular design. In addition to 6 principal views (front, back, top, bottom, right side, left side), any auxiliary views or section views may be included for the purposes of part definition and its communication.

4. 2. 3 Auxiliary Views

An auxiliary view is anorthographic view that is projected into any plane other than one of the six principal views. These views are typically used when an object contains some sort of inclined plane. Using the auxiliary view allows for that inclined plane (and any other significant features) can be projected in their true size and shape. The true size and shape of any feature in an engineering drawing can only be known when the Line of sight is perpendicular to the plane being referenced, as shown in Figure 4-4.

Isometric view of the object is also used as an auxiliary view in the engineering drawing. The isometric projection shows the object from angles in which the scales along each axis of the object are

equal, as shown in Figure 4-5. Isometric projection corresponds to rotation of the object by ± 45° about the vertical axis, followed by rotation of approximately ± 35.264° [= arcsin (tan30°)] about the horizontal axis starting from an orthographic projection view. "Isometric" comes from the Greek for "same measure". One of the factors that makes isometric drawings so attractive is the ease with which 60° angles can be constructed with only a compass and straightedge. Isometric projection is a type of axonometric projection and it is commonly used.

(From *English Communication for Mechanical Engineers* by L. Kang)

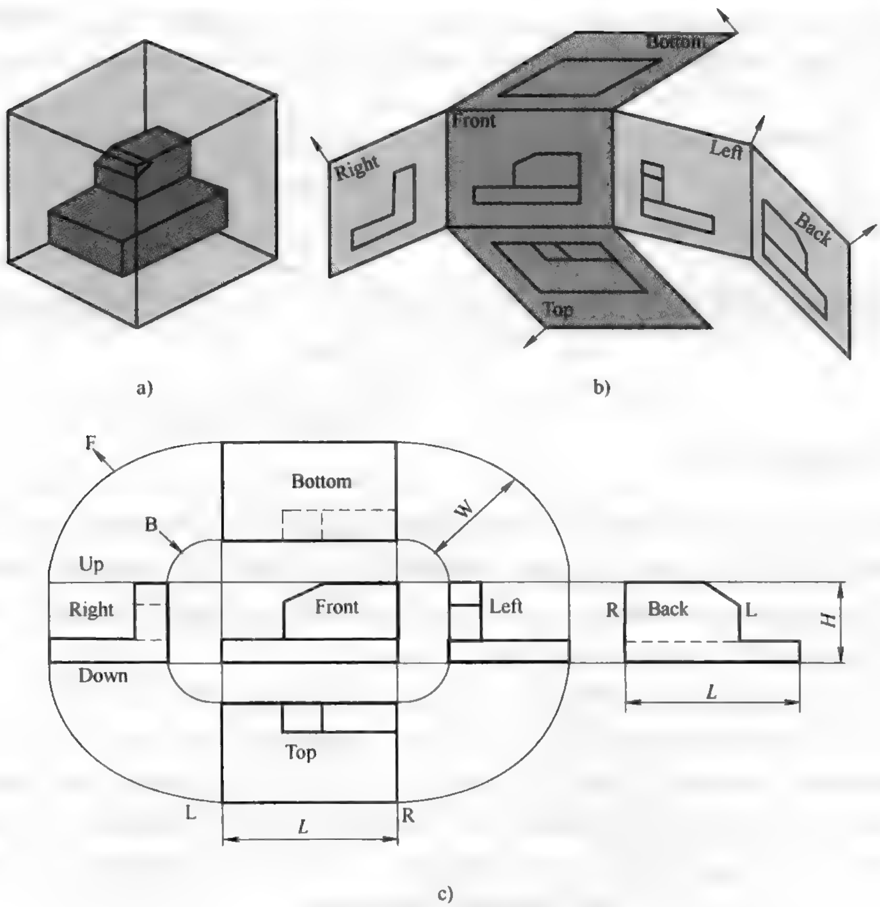


Figure 4-3 Six principle views

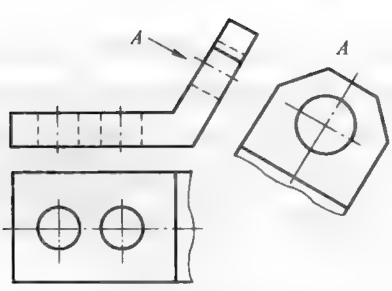


Figure 4-4 An auxiliary view

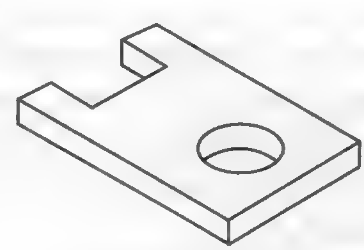


Figure 4-5 Isometric view

4.2.4 Sectional Views

Although the invisible feature of a simple object usually may be described on an exterior view by the use of hidden lines, it is unwise to depend on a perplexing mass of such lines to describe adequately the interior of a complicated object or an assembled mechanism. Whenever a representation becomes so confused that it is difficult to read, it is customary to make one or more of the views "in section". A view, "in section" is one obtained by imagining the object to have been cut by a cutting plane, the front portion being removed to reveal clearly the interior features. Figure 4-6 illustrates the use of an imaginary cutting plane. At this point it should be understood that a portion is shown removed only in a sectional view, not in any of the other views.

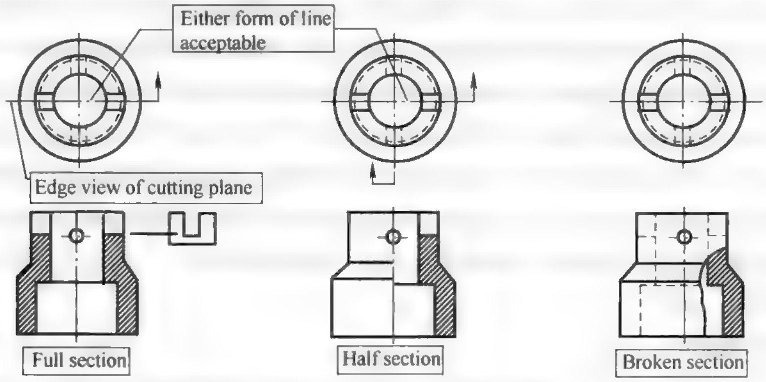


Figure 4-6 Types of sectional views⊖

When the cutting plane cuts an object lengthwise, the section obtained is commonly called a longitudinal section; when crosswise, it is called a cross section. It is designated as being either a full section, a half section, or a broken section. If the plane cuts entirely across the object, the section represented is known as a full section. If it cuts only halfway across a symmetrical object, the section is a half section. A broken section is a partial one, which is used when less than a half section is needed (Figure 4-6).

On a completed sectional view, fine section lines are drawn across the surface cut by the imaginary plane, to emphasize the contour of the interior.

1. Full Section

Since a cutting plane that cuts a full section passes entirely through an object, the resulting view will appear as illustrated in Figure 4-6. Although the plane usually passes along the main axis, it may be offset to reveal important features.

A full-sectional view, showing an object's characteristic shape, usually replaces an exterior front view; however, one of the other principal views, side or top, may be converted to a sectional view if some interior feature thus can be shown to better advantage or if such a view is needed in ad-

⊖ 该图为第三角画法。

dition to a sectioned front view.

The procedure in making a full-sectional view is simple, in that the sectional view is an orthographic one. The imaginary cut face of the object simply is shown as it would appear to an observer looking directly at it from a point an infinite distance away. In any sectional view, it is considered good practice to omit all invisible lines unless such lines are necessary to clarify the representation. Even then they should be used sparingly.

2. Half Section

The cutting plane for a half section removes one-quarter of an object. The plane cuts halfway through to the axis or center line so that half the finished sectional view appears in section and half appears as an external view (Figure 4-6). This type of sectional view is used when a view is needed showing both the exterior and interior construction of a symmetrical object. Good practice dictates that hidden lines be omitted from both halves of the view unless they are absolutely necessary for dimensioning purposes or for explaining the construction. Although the use of a solid object line to separate the two halves of a half section has been approved by the Society of Automotive Engineers and has been accepted by the American National Standards Institute, many draftsmen prefer to use a center line. They reason that the removal of a quarter of the object is theoretical and imaginary and that an actual edge, which would be implied by a solid line, does not exist. The center line is taken as denoting a theoretical edge.

3. Broken Section

A broken or partial section is used mainly to expose the interior of objects so constructed that less than a half section is required for a satisfactory description. The object theoretically is cut by a cutting plane and the front portion is removed by breaking it away. The "breaking away" gives an irregular boundary line to the section.

(From *Fundamentals of Engineering Drawing* by W. J. Luzadder)

4.3 Machine Drawings

There are two recognized classes of machine drawings: detail drawings and assembly drawings.

4.3.1 Detail Drawings

A detail drawing should give complete information for the manufacture of a part, describing with adequate dimensions of the part's size. Finished surfaces should be indicated and all necessary shop operations shown. The title should give the material of which the part is to be made and should state the number of the parts that are required for the production of an assembled unit of which the part is a member.

Since amachinist will ordinarily make one part at a time, it is advisable to detail each piece, regardless of its size, on a separate individual sheet. In some shops, however custom dictates that related parts be grouped on the same sheet, particularly when the parts form a unit in themselves. Other concerns sometimes group small parts of the same material together thus: castings on

one sheet, forgings on another, special fasteners on still another, and so on.

1. Steps for Making a Detail Drawing

With a design layout or original sketches as a guide, the procedure for making a detail drawing is as follows:

1) Select the views, remembering that, aside from the view showing the characteristic shape of the object, there should be as many additional views as are necessary to complete the shape description. These may be sectional views that reveal complicated interior construction, or auxiliary views of surfaces not fully described in any of the principal views.

2) Decide on a scale that will allow, without crowding, a balanced arrangement of necessary views and the location of dimensions and notes. Although very small parts should be drawn double-size or larger, to show detail and to allow for dimensions, a full-size scale should be used when possible. In general, the same scale should be used for pieces of the same size.

3) Draw the main center lines and block in the general outline of the views with light, sharp 6H pencil lines.

4) Draw main circles and arcs in finished weight.

5) Starting with the characteristic view, work back and forth from view to view until the shape of the object is completed. Lines whose definite location and length are known may be drawn in their finished weight.

6) Put in fillets and rounds.

7) Complete the view by darkening the object lines.

8) Draw extension and dimension lines.

9) Add arrowheads, dimensions, and notes.

10) Complete the title.

11) Check the entire drawing carefully.

2. One-View Drawing

Many parts, such as shafts, bolts, studs, and washers, may require only one properly dimensioned view. In the case of each of these parts, a note can imply the complete shape of the piece without sacrificing clearness. Most engineering departments, however, deem it better practice to show two views.

3. Detail Titles

Every detail drawing must give information not conveyed by the notes and dimensions, such as the name of the part, part number, material, number required, and so on. The method of recording and the location of this information on the drawing varies somewhat in different drafting rooms. It may be lettered either in the record strip or directly below the views.

4.3.2 Assembly Drawings

A drawing that shows the parts of a machine or machine unit assembled in their relative working positions is an assembly drawing. There are several types of such drawings: design assembly drawings, working assembly drawings, unit assembly drawings, installation diagrams, and so on.

A working assembly drawing, showing each piece completely dimensioned, is sometimes made for a simple mechanism or unit of related parts. No additional detail drawings of parts are required. A subassembly (Unit) drawing is an assembly drawing of a group of related parts that form a unit in a more complicated machine. Such a drawing would be made for the tail stock of a lathe, the clutch of an automobile, or the carburetor of an airplane. A set of assembly drawings thus takes the place of a complete assembly of a complex machine.

In an assembly, in order to identify each part, the number of the part is placed inside a circle called a "balloon". A line radiates from the balloon and ends on the part. The title block is located in the lower right corner of the sheet, it contains important organizational information such as: company name, part name, drawing number, sheet number, date, scale, drawn by, checked by, etc. Above the title block is the most important components—the list of materials, also known as the bill of materials or the parts list, is a table containing every part in the product. The list of materials normally contain: part number, part name, quantity required, material, and possible notes such as the specification for purchased fasteners.

(From *English Communication for Mechanical Engineers* by L. Kang & *Fundamentals of Engineering Drawing* by J. Luzadder)

4.4 Auto CAD

AutoCAD is a PC-based 2D and 3D mechanical design and drafting package. Geometric shapes and figures are created and modified for engineering drawing. A reduced instruction set processor (RISC), with a limited number of instructions, is built into the processor, reducing the response time to run some applications on the AutoCAD development system (ADS). Crosshairs and a mouse are used to locate geometric shapes—within the work area. An X-Y construction plane is used for the 2D mode that uses three-point origin placed by the user, known as the user coordinate system (UCS).

1. Command Structure

To support many applications, AutoCAD has an open architecture for easy customization of menus. The main menu is the screen menu, which includes the drawing editor, configuration, plot, file utility, and operating parameters menus. A dialogue box appears when selected items are chosen from the pull-down menus to assist the user. The following are examples of screen editor commands.

1) Set-up types of measurements or limits to the drawing area.

2) Blocks allows drawings to be grouped for insertion in other parts of the drawing.

3) Display commands refresh, redraw, or automatically redraw the screen and changes the viewing area.

4) Draw creates, modify geometric shapes and add text.

5) Edit allows modification of the actual drawing geometry using trim, move, rotate and extend commands.

6) Inquiry shows the location of a point or angle, evaluates areas, and gives database infor-

mation.

7) Layer changes the visibility, color, and line type of a layer.

8) Settings control the grid spacing, axis, size of the target box, and color.

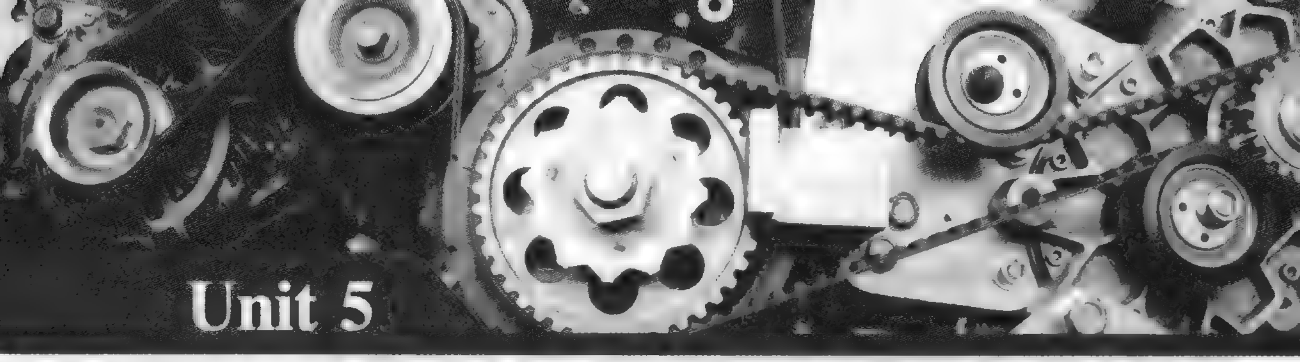
Other special menus are the utility or directory files, 3D for 3D drawings, and AutoShade to show shading or a shadowing from a chosen line of light.

2. Discussion

The AutoCAD commands are path dependent, e. g. , the undo command will remove the screen image and any previous drawing layers up to an earlier drawing level. Other features are AutoLISP and ADS. AutoLISP is an AutoCAD program that enhances the AutoCAD drawing and editing commands. For example, reference coordinates can be created and 2D spirals, holes, or slots in a 3D surface can be programmed and saved. AutoLISP is an interpretive system, with instructions being read, interpreted, validated and then executed in sequence.

ADS is an AutoCAD development system using a C language base interface into the core and an independent C compiler. The AutoCAD core holds the basic instruction set of the AutoCAD platform, maintains the database, and allows access to the data, using AutoCAD geometry commands, functions, and C options. Limited animation is available. Solid modeling and wire frames are created using simple Boolean rules to add subtract geometric shapes to a drawing shape, e. g. , a pipe is created by using cylinders to obtain an inside and outside diameter (ID, OD). These types of 2D forms used to generate solids or extruded solids of revolution.

(From *Engineering Design* by V. Miller)



Mechanics Foundations

5.1 Statics

5.1.1 Basic Terminologies

Length. Length is used to locate the position of a point in space and thereby describe the size of a physical system. Once a standard unit of length is defined, one can then use it to define distances and geometric properties of a body as multiples of this unit.

Time. Time is conceived as a succession of events. [1] Although the principles of statics are time independent, this quantity plays an important role in the study of dynamics.

Mass. Mass is a measure of a quantity of matter that is used to compare the action of one body with that of another. This property manifests itself as a gravitational attraction between two bodies and provides a measure of the resistance of matter to a change in velocity. [2]

Force. In general, force is considered as a "push" or "pull" exerted by one body on another. This interaction can occur when there is direct contact between the bodies, such as a person pushing on a wall, or it can occur through a distance when the bodies are physically separated. Examples of the latter type include gravitational, electrical, and magnetic forces. In any case, a force is completely characterized by its magnitude, direction, and point of application. [3]

Idealizations. Models or idealizations are used in mechanics in order to simplify application of the theory. Here, we will consider three important idealizations.

(1) **Particle.** A particle has a mass, but a size that can be neglected. For example, the size of the earth is insignificant compared to the size of its orbit, and therefore the earth can be modeled as a particle when studying its orbital motion. When a body is idealized as a particle, the principles of mechanics reduce to a rather simplified form since the geometry of the body will not be involved in the analysis of the problem.

(2) **Rigid Body.** A rigid body can be considered as a combination of a large number of particles in which all the particles remain at a fixed distance from one another, both before and after applying a load. [4] This model is important because the material properties of anybody that is assumed to be rigid will not have to be considered when studying the effects of forces acting on the body. In most cases, the actual deformations occurring in structures, machines, mechanisms, and the like

are relatively small, and the rigid-body assumption is suitable for analysis.

(3) **Concentrated Force.** A concentrated force represents the effect of a loading which is assumed to act at a point on a body. We can represent a load by a concentrated force, provided the area over which the load is applied is very small compared to the overall size of the body. ⑤ An example would be the contact force between a wheel and the ground.

SI Units. The International System of units, abbreviated SI after the French "Système International d'Unités", is a modern version of the metric system which has received worldwide recognition. The SI system defines length in meters (m), time in seconds (s), and mass in kilograms (kg).

Scalar and Vector. A scalar is any positive or negative physical quantity that can be completely specified by its magnitude. Examples of scalar quantities include length, mass, and time. A vector is any physical quantity that requires both a magnitude and a direction for its complete description. Examples of vectors encountered in statics are force, position, and moment. A vector is shown graphically by an arrow: the length of the arrow represents the magnitude of the vector, and the angle θ between the vector and a fixed axis defines the direction of its line of action, and the head or tip of the arrow indicates the sense of direction of the vector, as shown in Figure 5-1.

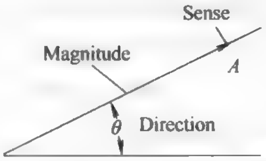


Figure 5-1 Graphical expression of a vector

Right-Handed Coordinate System. We will use a right-handed coordinate system to develop the theory of vector algebra that follows. A rectangular coordinate system is said to be right-handed if the thumb of the right hand points in the direction of the positive z axis when the right-hand fingers are curled about this axis and directed from the positive x towards the positive y axis.

Dot Product. The dot product defines a particular method for "multiplying" two vectors.

Moment of a Force. When a force is applied to a body it will produce a tendency for the body to rotate about a point that is not on the line of action of the force. This tendency to rotate is sometimes called a torque, but most often it is called the moment of a force or simply the moment. The magnitude of the moment is the product of the applied force F and the moment arm d. The direction of the moment is defined by its moment axis, which is perpendicular to the plane that contains the force F and its moment arm d.

Moment of a Couple. The moment produced by a couple is called a couple moment. We can determine its value by finding the sum of the moments of both couple forces about any arbitrary point.

Characteristics of Dry Friction. Friction is a force that resists the movement of two contacting surfaces that slide relative to one another. This force always acts tangent to the surface at the points of contact and is directed so as to oppose the possible or existing motion between the surfaces. ⑥

Equilibrium. The effect of the distributed normal and frictional loadings is indicated by their resultants $\boldsymbol{N}$ and $\boldsymbol{F}$ on the free-body diagram.

Impending Motion. In cases where the surfaces of contact are rather "slippery", the frictional

force $\boldsymbol{F}$ may not be great enough to balance the applied force $\boldsymbol{P}$, and consequently the block will tend to slip. In other words, as P is slowly increased, F corresponding increases until it attains a certain maximum value F_S, called the limiting static frictional force.

Motion. If the magnitude of $\boldsymbol{P}$ acting on the block is increased so that it becomes slightly greater than F_S, the frictional force at the contacting surface will drop to a smaller value F_k, called the kinetic frictional force.

Center of Gravity. A body is composed of an infinite number of particles of differential size, and the body is located within a gravitational field. Then each of these particles will have a weight dW. These weights will form an approximately parallel force system, and the resultant of this system is the total weight of the body, which passed through a single point called the center of gravity.

5.1.2 Important Principles

Newton's Three Laws of Motion. Engineering mechanics is formulated on the basic of Newton's three laws of motion, the validity of which is based on experimental observation. These laws apply to the motion of a particle as measured from a non-accelerating reference frame. They may be briefly stated as follows.

First Law. A particle originally at rest, or moving in a straight line with constant velocity, tends to remain in this state provided the particle is not subjected to an unbalanced force, as shown in Figure 5-2.

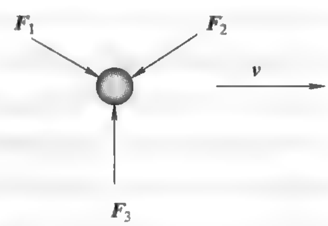


Figure 5-2 Equilibrium of forces

Second Law. A particle acted upon by an unbalanced force $\boldsymbol{F}$ experiences an acceleration $\boldsymbol{a}$ that has the same direction as the force and a magnitude that is directly proportional to the force, as shown in Figure 5-3.

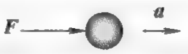


Figure 5-3 Accelerated motion caused by unbalanced force

Third Law. The mutual forces of action and reaction between two particles are equal, opposite, and collinear, as shown in Figure 5-4.

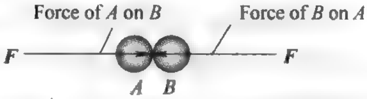


Figure 5-4 Action-reaction force

Weight. According to Newton's Law of Gravitational Attraction, any two particles or bodies have mutual attractive (gravitational) forces acting between them. In the case of a particle located at or near the surface of the earth. However, the only gravitational force having any sizable magnitude is that between the earth and the particle. Consequently, this force, termed the weight, will be the only gravitational force considered in our study of mechanics.

Multiplication and Division of a Vector by a Scalar. If a vector is multiplied by a positive scalar, its magnitude is increased by that amount. When multiplied by a negative scalar it will also

change the directional sense of the vector.

Vector Addition. All vector quantities obey the parallelogram law of addition. To illustrate, two "component" vectors $\boldsymbol{A}$ and $\boldsymbol{B}$ in Figure 5-5 are added to form a "resultant" vector $\boldsymbol{R}=\boldsymbol{A}+\boldsymbol{B}$ using the following procedure:

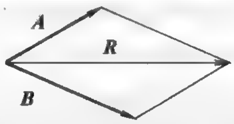


Figure 5-5 Parallelogram law of vector addition, $\boldsymbol{R}=\boldsymbol{A}+\boldsymbol{B}$

1) First join the tails of the components at a point so that it makes them concurrent.

2) From join head of $\boldsymbol{B}$, draw a line parallel to $\boldsymbol{A}$. Draw another line from the head of $\boldsymbol{A}$ that is parallel to $\boldsymbol{B}$. These two lines intersect at point P to form the adjacent sides of a parallelogram.

3) The diagonal of this parallelogram that extends to P forms $\boldsymbol{R}$, which then represents the resultant vector $\boldsymbol{R}=\boldsymbol{A}+\boldsymbol{B}$.

Vector Subtraction. The resultant of the difference between two vectors $\boldsymbol{A}$ and $\boldsymbol{B}$ of the same type may be expressed as

$$\boldsymbol{R}'=\boldsymbol{A}-\boldsymbol{B}=\boldsymbol{A}+(-\boldsymbol{B})$$

Finding a Resultant Force. The two component forces $\boldsymbol{F}_1$ and $\boldsymbol{F}_2$ acting on the pin can be added together to form the resultant force $\boldsymbol{F}_R=\boldsymbol{F}_1+\boldsymbol{F}_2$. From this construction, or using the triangle rule, as shown in Figure 5-6, we can apply the Law of Cosines or the Law of Sines to the triangle in order to obtain the magnitude of the resultant force and its direction.

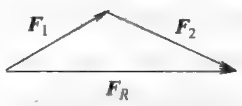


Figure 5-6 Formation of resultant force using triangle rule

Addition of Several Forces. If more than two forces are to be added, successive applications of the parallelogram law can be carried out in order to obtain the resultant force.

Principle of Moments. A concept often used in mechanics is the principle of moments, which is sometimes referred to as Varignon's theorem since it was originally developed by the French mathematician Varignon (1654 – 1722). It states that the moment of a force about a point is equal to the sum of the moments of the components of the force about the point. This theorem can be proven easily using the vector cross product since the cross product obeys the distributive law.

Equations of Equilibrium. Two equations are both necessary and sufficient for the equilibrium of a rigid body, namely, $\sum \boldsymbol{F}=0$ and $\sum \boldsymbol{M}_O=0$.

(From *Statics and Mechanics of Materials* by R. C. Hibbeler)

5.2 Mechanics of Material

5.2.1 Basic Terminologies

Normal Force, *N.* This force acts perpendicular to the area. It is developed whenever the external loads tend to push or pull on the two segments of the body.

Shear Force, *V*. The shear force lies in the plane of the area and it is developed when the external loads tend to cause the two segments of the body to slide over one another.

Torsional Moment or Torque, *T*. This effect is developed when the external loads tend to twist one segment of the body with respect to the other about an axis perpendicular to the area.

Bending Moment, *M*. The bending moment is caused by the external loads that tend to bend the body about an axis lying within the plane of the area.

Normal Stress, σ. The intensity of the force acting normal to ΔA is defined as the normal stress.

Shear Stress, τ. The intensity of force acting tangent to ΔA is called the shear stress.

Allowable Stress. To properly design a structural member or mechanical element it is necessary to restrict the stress in the material to a level that will be safe. To ensure this safety, it is therefore necessary to choose an allowable stress that restricts the applied load to one that is less than the load the member can fully support.

Shear Strain. Deformations not only cause line segments to elongate or contract, but they also cause them to change direction. If we select two line segments that are originally perpendicular to one another, then the change in angle that occurs between these two line segments is referred to as shear strain.

Ductile Materials. Any material that can be subjected to large strains before it fractures is called a ductile material.

Brittle Materials. Materials that exhibit little or no yielding before failure are referred to as brittle materials.

Strain Energy. As a material is deformed by an external loading, it tends to store energy internally throughout its volume. Since this energy is related to the strain in the material, it is referred to as strain energy.

Poisson's Ratio. When a deformable body is subjected to an axial tensile force, not only does it elongate but it also contrasts laterally. For example, if a rubber band is stretched, it can be noted that both the thickness and width of the band are decreased. Likewise, a compressive force acting on a body causes it to contract in the direction of the force and yet its sides expand laterally.

Consider a bar having an original radius r and length L and subjected to the tensile force $\boldsymbol{P}$. This force elongates the bar by an amount δ, and its radius contracts by an amount δ'. Strain in the longitudinal or axial direction and in the lateral or radial direction are, respectively,

$$\varepsilon_{\text{long}} = \frac{\delta}{L} \text{ and } \varepsilon_{\text{lat}} = \frac{\delta'}{r}$$

In the early 1800s, the French scientist S. D. Poisson realized that within the elastic range the ratio of these strains is a constant, since the deformations δ and δ' are proportional. This constant is referred to as Poisson's ratio, ν (nu), and it has a numerical value that is unique for a particular material that is both homogeneous and isotropic. Stated mathematically it is

$$\nu = -\frac{\varepsilon_{\text{lat}}}{\varepsilon_{\text{long}}}$$

The negative sign is included here since longitudinal elongation (positive strain) causes lateral contraction (negative strain), and vice versa. Notice that thee strains are caused only by the axial or longitudinal force $\boldsymbol{P}$, i. e. , no force or stress acts in a lateral direction in order to strain the material in this direction.

Beams. Members that are slender and support loading that are applied perpendicular to their longitudinal axis are called beams. In general, beams are long, straight bars having a constant cross-sectional area. Often they are classified as to how they are supported. For example, a simply supported beam is pinned at one end and roller supported at the other, as shown in Figure 5-7, a cantilevered beam is fixed at one end and free at the other, and an overhanging beam is fixed at one or both of its ends freely extended over the supports. Beams are considered among the most important of all structural elements. They are used to support the floor of a building, the deck of a bridge, or the wing of an aircraft. Also, the axle of an automobile, the boom of a crane, even many of the bones of the body act as beams.

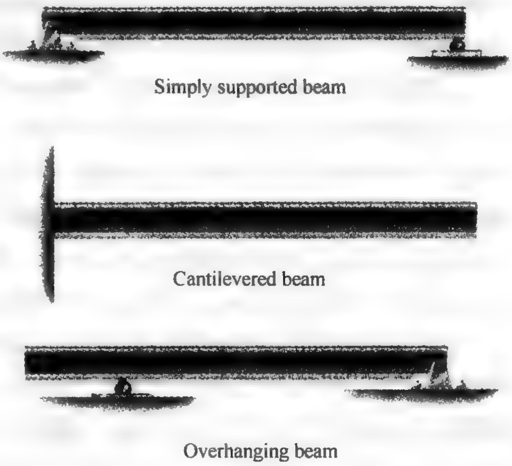


Figure 5-7 Beam classification by how they are supported

Shear and Moment Diagrams. Because of the applied loadings, beams develop an internal shear force and bending moment that, in general, vary from point to point along the axis of the beam. In order to properly design a beam it therefore becomes necessary to determine the maximum shear and moment in the beam. One way to do this is to express shear force $\boldsymbol{V}$ and bending moment $\boldsymbol{M}$ as functions of their arbitrary position x along the beam's axis. These shear and moment functions can then be plotted and represented by graphs called shear and moment diagrams. The maximum values of $\boldsymbol{V}$ and $\boldsymbol{M}$ can then be obtained from these graphs. Also, since the shear and moment diagrams provide detailed information about the variation of the shear and moment along the beam's axis, they are often used by engineers to decide where to place reinforcement materials within the beam or how to proportion the size of the beam at various points along its length.

5.2.2 Important Principles

Average Normal Stress in an Axially Loaded Bar.

$$\sigma = \frac{\boldsymbol{P}}{A}$$

Where σ is the average normal stress at any point on the cross-sectional area. $\boldsymbol{P}$ is the internal resultant normal force, which acts through the centroid of the cross-sectional area, and determined using the method of sections and the equations of equilibrium. A is the cross-sectional area of the bar where σ is determined.

Average Shear Stress.

$$\tau_{avg} = \frac{V}{A}$$

Where τ_{avg} is the average shear stress at the section, which is assumed to be the same at each point located on the section. V is the internal resultant shear force on the section determined from the equations of equilibrium and A is the area of the section.

Hooke's Law. The stress-strain diagrams for most engineering materials exhibit a linear relationship between stress and strain within the elastic region. Consequently, an increase in stress causes a proportionate increase in strain. This fact was discovered by Robert Hooke in 1676 using springs and is known as Hooke's law. It may be expressed mathematically as $\sigma = E\varepsilon$. Here E represents the constant of proportionality, which is called the modulus of elasticity or Young's modulus, named after Thomas Young, who published an account of it in 1807.

Saint-Venant's Principle. Saint-Venant's Principle, named after the French elasticity theorist Adhémar Jean Claude Barré de Saint-Venant can be stated as saying that: the difference between the effects of two different but statically equivalent loads becomes very small at sufficiently large distances from load.

Principle of Superposition. The principle of superposition is often used to determine the stress or displacement at a point in a member when the member is subjected to a complicated loading. By subdividing the loading into components, the principle of superposition states that the resultant stress or displacement at the point can be determined by algebraically summing the stress or displacement caused by each load component applied separately to the member.

The following two conditions must be satisfied if the principle of superposition is to be applied: The loading must be linearly related to the stress or displacement that is to be determined; the loading must not significantly change the original geometry or configuration of the member.

The Torsion Formula.

$$\tau_{max} = \frac{Tc}{J}$$

Where τ_{max} is the maximum shear stress in the shaft, which occurs at the outer surface. T is the resultant internal torque acting at the cross section, and the subscript "C" represents the parameter at the outer radius of the shaft. Value of T is determined from the method of sections and the equation of moment equilibrium applied about the shaft's longitudinal axis. J is the polar moment of inertia of the cross-sectional area.

$$\tau = \frac{T\rho}{J}$$

Either of the above two equations is often referred to as the torsion formula. Recall that it is used only if the shaft is circular and the material is homogeneous and behaves in a linear elastic manner, since the derivation is based on Hooke's law.

The Flexure Formula. The equation relates the stress distribution in a beam to the internal resultant bending moment acting on the beam's cross section.

$$\sigma_{max} = \frac{Mc}{I}$$

Where

σ_{max} = the maximum normal stress in the member, which occurs at a point on the cross-sectional area farthest away from the neutral axis.

M = the resultant internal moment, determined from the method of sections and the equations of equilibrium, and calculated about the neutral axis of the cross section.

c = the perpendicular distance from the neutral axis to a point farthest away from the neutral axis. This is where σ_{max} acts.

I = the moment of inertia of the cross-sectional area about neutral axis.

The Shear Formula.

$$\tau = \frac{VQ}{It}$$

Where

τ = the shear stress in the member at the point located a distance y' from the neutral axis. This stress is assumed to be constant and therefore averaged across the width t of the member.

V = the internal resultant shear force, determined from the method of sections and the equations of equilibrium.

I = the moment of inertia of the entire cross-sectional area calculated about the neutral axis.

t = the width of the member's cross-sectional area, measured at the point where τ is to be determined.

$Q = \overline{y}'A'$, where A' is the area of the top (or bottom) portion of the member's cross-sectional area, above (or below) the section plane where t is measured, and $\overline{y}'$ is the distance from the neutral axis to the centroid of A'.

The above equation is referred to as the shear formula. Although in the derivation we considered only the shear stressed acting on the beam's longitudinal plane, the formula applies as well for finding the transverse shear stress on the beam's cross-section. Recall that these stresses are complementary and numerically equal.

Also, because the flexure formula was used in the derivation, it is necessary that the material behave in a linear elastic manner and have a modulus of elasticity that is the same in tension as it is in compression.

(From *Statics and Mechanics of Materials* by R. C. Hibbeler)

5.3 Fluid Mechanics and Applications

5.3.1 Basic Terminologies

Compressible and Incompressible Fluids. Fluid mechanics deals with both incompressible and compressible fluids, that is, with liquids and gases of either constant or variable densi-

ty. Although there is no such thing in reality as an incompressible fluid, we use this term where the change in density with pressure is so small as to be negligible. This is usually the case with liquids. We may also consider gases to be incompressible when the pressure variation is small compared with the absolute pressure.

Density, Specific Weight, Specific Volume, and Specific Gravity. The density, or more strictly mass density, of a fluid is its mass per unit volume, while the specific weight is its weight per unit volume. Specific volume is the volume occupied by a unit mass of fluid. We commonly apply it to gases, and it is the reciprocal of density. Specific gravity of a liquid is the dimensionless ratio of its density to the water density at standard temperature (4℃).

Viscosity. The viscosity of a fluid is a measure of its resistance to shear or angular deformation.

Ideal Fluid. An ideal fluid is usually defined as a fluid in which there is no friction; it is inviscid (its viscosity is zero).

Surface Tension. Liquids have cohesion and adhesion, both of which are forms of molecular attraction. Cohesion enables a liquid to resist tensile stress, while adhesion enables it to adhere to another body. At the interface between a liquid and a gas, i. e. , at the liquids surface, and at the interface between two immiscible liquids, the out-of-balance attraction force between molecules forms an imaginary surface film which exerts a tension force in the surface. This liquid property is known as surface tension.

Absolute and Gage Pressures. If we measure pressure relative to absolute zero, we call it absolute pressure; when we measure it relative to atmospheric pressure as a base, we call it gage pressure.

Center of Pressure. The point of application of the resultant pressure force on a submerged area is called the center of pressure.

Path Lines, Streamlines, and Streak Lines. A path line is the trace made by a single particle over a period of time. Streamlines show the mean direction of a number of particles at the same instant of time. In experimental fluid mechanics, a dye or other tracer is frequently injected into the flow to trace the motion of the fluid particles. If the flow is laminar, a ribbon of color results. This is called a streak line, or filament line.

Geometric Similarity. One of the desirable features in model studies is that we have geometric similarity, which means that the model and its prototype have identical shapes but differ only in size. ⑦ The important consideration is that the flow patterns must be geometrically similar.

Kinematic Similarity. Kinematic similarity implies that, in addition to geometric similarity, the ratio of the velocities at all corresponding points in the flows are the same.

Dynamic Similarity. Two systems have dynamic similarity if, in addition to kinematic similarity, corresponding forces are in the same ratio in both. ⑧

Reynolds Number. In the flow of a fluid through a completely filled conduit, gravity does not affect the flow pattern. Also, since there are no free liquid surfaces, capillarity is obviously of no practical importance. Therefore the significant forces are inertia and fluid friction due to viscosity. The same is true of an airplane traveling at speeds below that at which much air compression

occurs. Also, for a submarine submerged far enough that it does not produce waves on the surface, the only forces involved are those of friction and inertia.

For the ratio of inertia forces to viscous forces, we call the resulting parameter the Reynolds number, or *Re*, in honor of Osborne Reynolds (1842 – 1912), the English physicist and professor who presented this in a publication of his experimental work in 1882.

Critical Reynolds Number. The upper critical Reynolds number is really indeterminate and depends on the care taken to prevent any initial disturbance from affecting the flow. Its value is normally about 4, 000, but experimenters have maintained laminar flow in circular pipes up values of *Re* as high as 50, 000. However, in such cases this type of flow is inherently unstable, and the least disturbance will transform it instantly into turbulent flow. On the other hand, it is practically impossible for turbulent flow in a straight pipe to persist at values of *Re* much below 2, 000, because any turbulence that occurs is damped out by viscous friction. This lower value is thus much more definite than the higher one, and is the real dividing point between the two types of flow. So we define this lower value as the true critical Reynolds number.

Boundary Layer. We described the boundary layer as a very thin layer of fluid adjacent to a surface, in which viscosity is important, while we can consider the fluid outside this layer as frictionless or ideal. [9] This concept, originated by Ludwig Prandtl in 1904, is one of the important advances in modern fluid mechanics.

Pitot Tubes. One means of measuring the local velocity in a flowing fluid is the pitot tube, named after its inventor Henri Pitot (1695 – 1771), a French physicist who used a bent tube in 1732 to measure velocities in the River Seine.

Venturi Meter. The converging tube is an efficient device for converting pressure head to velocity head, while the diverging tube converts velocity head to pressure head. The two may be combined to form a venturi tube, named after Giovanni B. Venturi (1746 – 1822), an Italian physicist who investigated its principle about 1791. It was applied to the measurement of water by an American engineer, Clemens Herschel, in 1886. It consists of a tube with a constricted throat, which produces an increased velocity accompanied by a reduction in pressure, followed by a gradually diverging portion in which the velocity is transformed back into pressure with slight friction loss. [10]

As there is a definite relation between the pressure differential and the rate of flow, the tube may be made to serve as a metering device known as a venturi meter. The venturi meter is used for measuring the rate of flow of both compressible and incompressible fluids.

5.3.2 Important Principles

Property Relations for Perfect Gases. The various properties of a gas, listed below, are related to one another. They differ for each gas. When the conditions of most real gases are far removed from the liquid phase, these relations closely approximate those of hypothetical perfect gases. Perfect gases, are here (and often) defined to have constant specific heats and to obey the perfect-gas law,

$$\frac{p}{\rho} = pv = RT$$

Where p is absolute pressure, ρ is the density, and v is the specific volume. R is a gas constant, the value of which depends upon the particular gas. T is the absolute temperatthre in degrees Rankine or Kelvin.

Newton's Equation of Viscosity. If we now introduce a constant of proportionality (absolute viscosity) μ, we can express the shearing stress τ between any two thin sheets of fluid by Newton's equation of viscosity:

$$\tau = \frac{F}{A} = \mu \frac{U}{Y} = \mu \frac{\mathrm{d}u}{\mathrm{d}y}$$

In many problems involving the absolute viscosity is divided by density. This ratio defines the kinematic viscosity v, so called because force is not involved, the only dimensions being length and time, as in kinematics.

Pressure at a Point Is the Same in All Directions. In a solid, because of the possibility of tangential stresses between adjacent particles, the stresses at a given point may be different in different directions. But no tangential stresses can exist in a fluid at rest, and the only forces between adjacent surfaces are pressure forces normal to the surfaces. Therefore the pressure at any point in a fluid at rest is the same in every direction.

5.3.3 Applications—Classical Hydraulic Machinery

1. Description of Centrifugal and Axial-Flow Pumps

The rotating element of acentrifugal pump is called the impeller. The impeller may be shaped to force water outward in a plane at right angles to its axis (radial flow), to give the water an axial as well as radial velocity (mixed flow), or to induce a spiral flow on coaxial cylinders in an axial direction (axial flow). Radial-flow and mixed-flow machines are commonly referred to as centrifugal pumps, while axial-flow machines are called axial-flow pumps or propeller pumps. Radial- and mixed-flow impellers may be either open or closed. The open impeller consists of a hub to which vanes are attached, while the closed impeller has plates (or shrouds) on each side of the vanes. The open impeller does not have as high an efficiency as the closed impeller, but it is less likely to become clogged and hence is suited to handling liquids containing solids.

Radial-flow pumps are provided with a spiral casing, often referred to as a volute casing, which guides the flow from the impeller to the discharge pipe. The ever increasing flow cross section around the casing tends to maintain a constant velocity within the casing. This helps to provide relatively smooth flow conditions at exit from the impeller. Some pumps have diffuser vanes instead of a volute casing. Such pumps are known as turbine pumps. Some radial pumps are of the double-suction type. They have identical, mirror-image impellers placed back to back. Water enters the pump from both sides and is discharged into a volute casing or diffuser vanes. The advantage of the double-suction pump is the reduced mechanical friction that results because the thrust on the bearings is balanced.

Typical centrifugal-flow and axial-flow pump installations' pumps can be single-stage or multistage. A single-stage pump has only one impeller, while a multistage has two or more impellers arranged in such a way that the discharge from one impeller enters the eye of the next

impeller. Deep-well pumps, a type of turbine pump, are usually multistage, having several impellers on a vertical shaft suspended from a prime mover, usually an electric motor, located at the ground surface. Each impeller discharges into a fixed-vane diffuser, or bowl, coaxial with the drive shaft, which directs water to the next impeller.

Proper arrangement of the suction and discharge piping is necessary if a centrifugal pump is to operate at best efficiency. For economy, the diameter of the pump casing at suction and discharge is often smaller than that of the pipe to which it is attached. If there is ahorizontal reducer between the suction and the pump, we should use an eccentric reducer to prevent air accumulation. A foot valve (check valve) can be installed in the suction pipe to prevent water from leaving the pump when it is stopped. The discharge pipe is usually provided with a check valve and a gate valve. The check valve prevents backflow through the pump if there is a power failure. Suction pipes taking water from a sump or reservoir are usually provided with a screen to prevent entrance of debris that might clog the pump.

Axial-flow pumps usually have only two to four blades and, hence, large unobstructed passages that permit handling of water containing debris without clogging. The blades of some large axial-flow pumps are adjustable to permit setting the pitch for the best efficiency under existing conditions.

2. Hydraulic Turbines

There are two basic types of hydraulic turbines. In the impulse turbine a free jet of water impinges on the revolving element of the machine, which is exposed to atmospheric pressure. In a reaction turbine, flow takes place under pressure in a closed chamber. Although the energy delivered to an impulse turbine is all kinetic, while the reaction turbine utilizes pressure energy as well as kinetic energy, the action of both turbines depends on a change in the momentum of the water so that a dynamic force is exerted on the rotating element, or runner. The runner of a reaction turbine is similar in design, but not identical to pump impeller. By rotating either rotor (i. e., centrifugal pump or reaction turbine) in the reverse direction, the machine assumes the function of its counterpart. The efficiency, however, will be small in the reverse mode because the geometric shape of the rotating element and it surrounding casing will not be optimum.

Turbines are operated at constant speed. In the United States, 60-cycle (cycles/sec or Hz) electric current is most common, and under such conditions the rotative speed n of a turbine in revolutions per minute is given by $N = 7200/n$, where N is the number of poles in the generator and must be an even integer. Most 60-Hz generators have from 12 to 96 poles. In many parts of the world, 50-cycle current is used, in which case $N = 6000/n$. The power demand of an electric distribution system varies throughout the day: it is usually higher during daylight hours and lower at night. Consequently there is a variation in the "load" on the system. In a large system the variation in load can be accommodated by varying the number of generators in operation. Even so, the load on a single generator may vary with time. Therefore, if the generator is driven by a hydraulic turbine, in order to maintain constant speed, there must be some way in which the flow passing through the turbine can be adjusted to regulate the power output of the turbine.

(From *Fluid Mechanics with Engineering Applications*
by E. J. Finnemore and J. B. Franzini)

5.4 Thermodynamics

5.4.1 Basic Terminologies

Concept of Temperature. The concept of temperature is rich in interpretations and levels of abstraction. In its anthropomorphic understanding, temperature is a measure of the hotness of a given macroscopic object, as felt by the human body. Even though coldness is commonly used to express some temperatures we prefer to avoid the word "coldness" for reasons provided by statistical mechanics. In the microscopic point of view, temperature is associated with the agitation, vibration, or motion of the object's constituent particles. Accordingly, coldness means "less hotness" . To avoid ambiguity, it is suggested that the word "coldness" be avoided and let the concept of temperature be understood as the degree of hotness of an object above zero hotness.

Celsius Temperature Scale. The Celsius temperature scale, named after the Swedish astronomer Anders Celsius, was the international temperature scale prior to the introduction of the Kelvin scale in 1954. The Kelvin temperature scale is based upon a degree of the same magnitude as that of the Celsius scale; the fixed point was shifted from the ice point of water (273.15K) to the triple point of water, which was defined to be 0.01℃ above the ice point of water, that is 273.16K. In effect, the numerical values of the normal freezing point of water and the normal boiling point of water were left to be determined by experiment, rather than being defined fixed temperatures. So, if θ denotes the Celsius temperature, the relationship between the Celsius scale and the Kelvin scale is simply

$$\theta(℃) = T(\mathrm{K}) - 273.15$$

Thermocouple. A thermocouple is calibrated by measuring the thermal emf at the test junction at various known temperatures, the reference junction being kept at 0℃. The advantage of a thermocouple is that it quite rapidly comes to thermal equilibrium with the system whose temperature is to be measured, because its mass is small. Furthermore, the emf of the thermocouple is adaptable to electrical circuits, which monitor and control temperatures in many industrial, commercial, and residential furnaces, ovens, and cooling units. The disadvantage, as far as scientific temperature measurement is concerned, is that the imprecision is about 0.2K, which is five to ten times larger than the imprecision of the platinum resistance thermometer at higher temperatures. Therefore, the thermocouple is no longer a standard thermometer used in the International Temperature Scale of 1990.

Thermodynamic Equilibrium. Suppose that experiments have been performed on a thermodynamic system and that the coordinates necessary and sufficient for a macroscopic description have been determined. When these coordinates change in any way whatsoever, either spontaneously or by virtue of outside influence, the system is said to undergo a change of state. When a system is not influenced in any way by its surroundings, it is said to be isolated. In practical applications of thermodynamics, isolated systems are of little importance. We usually have to deal with a system that is influenced in some way by its surroundings. In general, the surroundings may exert forces on the sys-

tem or provide contact between the system and a body at some definite temperature. When the state of a system changes, interactions usually take place between the system and its surroundings.

When there is no unbalanced force or torque in the interior of a system and also none between a system and its surroundings, the system is said to be in a state of mechanical equilibrium. When a system in mechanical equilibrium does not tend to undergo a spontaneous change of internal structure, such as diffusion or solution, however slow, then it is said to be in a state of chemical equilibrium. Thermal equilibrium exists when there is no spontaneous change in the coordinates of a system in mechanical and chemical equilibrium when it is separated from its surroundings by diathermic walls.

When the conditions for all three types of equilibrium are satisfied, the system is said to be in a state of thermodynamic equilibrium; in this condition, it is apparent that there will be no tendency whatever for any change of state, either of system or of the surroundings, to occur. States of thermodynamic equilibrium can be described in terms of macroscopic coordinates that do not involve the time, that is in terms of thermodynamic coordinates.

Work. If a system undergoes a displacement under the action of a force, work is said to be done, the amount of work being equal to the product of the force and the component of the displacement parallel to the force. If a system as a whole exerts a force on its surroundings and a displacement takes place, the work that is done either by the system or on the system is called external work. Thus, a gas, confined in a cylinder and at uniform pressure, while expanding and imparting motion to a piston does external work on its surroundings. The work done, however, by one part of a system on another part is called internal work.

Conversion of Heat into Work. Each of the processes that constitute a cycle involves either the performance of work or a flow of heat between the system and its surroundings, which consist of a heat reservoir at a higher temperature than the system (a "high-temperature reservoir") and a heat reservoir at a lower temperature than the system (a "low-temperature reservoir"). [11]

If the heat exchanged between the high-temperature reservoir and the system $|Q_H|$ is larger than the heat exchanged between the low-temperature reservoir and the system $|Q_L|$ and if the work exchanged between the system and the surrounding is done by the system, then the machine that causes the system to undergo the cycle is called a heat engine. The purpose of a heat engine is to deliver work continuously to the surroundings by performing the same cycle over and over again. The net work in the cycle is the output, and the heat absorbed from the high-temperature reservoir by the system is the input.

Carnot Cycle. A Carnot cycle is a set of processes that can be performed by any thermodynamic system whatsoever, whether hydrostatic, chemical, electrical, magnetic, or otherwise. The system or working substance is imagined first to be in thermal equilibrium with a reservoir at the low temperature. Four processes are then performed in the following order:

1) A reversible adiabatic process is performed in such a direction that the temperature rises to that of the high-temperature reservoir T_H.

2) The working substance is maintained in contact with the reservoir at T_H, and a reversible

isothermal process is performed in such a direction and to such an extent that heat $|Q_H|$ is absorbed from the reservoir.

3) A reversible adiabatic process is performed in a direction opposite to process 1 until the temperature drops to that of the low-temperature reservoir, T_L.

4) The working substance is maintained in contact with the reservoir at T_L, and a reversible isothermal process is performed in a direction opposite to process 2 until the working substance and the surroundings are in their initial states. During this process, heat $|Q_L|$ is rejected to the low-temperature reservoir.

5.4.2 Important Principles

Thermal Equilibrium and the Zeroth Law. Two systems in thermal equilibrium with the third are in thermal equilibrium with each other. As suggested by Ralph Fowler, this postulate of transitive thermal equilibrium has been numbered the zeroth law of thermodynamic, which establishes the basis for the concept of temperature and for the use of thermometers.

The postulate of thermal equilibrium is numbered the zeroth law, rather than the first law, because of the historical development in the understanding of the logical order of the laws of thermodynamics. The first law of thermodynamics, which establishes the conservation of energy, including heat, was clearly formulated in 1848 by Hermann Helmholtz and William Thomson (later Lord Kelvin) using experimental data gathered by James Prescott Joule (1843 - 1849) and insight provided by Julius Mayer (1842). The second law of thermodynamics was postulated earlier (1824) in Sadi Carnot's study of the working of steam engines. Logically, Carnot's principle must follow the first law if his principle is expressed as a restriction on the means by which energy can be communicated while still being conserved. As the postulates of thermodynamics were developed further, it was realized by Fowler (1931) that thermal equilibrium had to be defined before the first law could be stated. Unable to renumber the two previously established laws of thermodynamics, he was forced to adopt zero as the number of his law. It is unlikely that future developments will raise the possibility of the "minus first" law of thermodynamics.

Equation of State. Imagine, for the sake of simplicity, a constant mass of gas, that is, a closed system, in a vessel so equipped that the pressure p, volume V, and temperature T may be easily measured. If we fix the volume at some arbitrary value and cause the temperature to assume an arbitrarily chosen value, then we shall not be able to vary the pressure at all. Once V and T are chosen by us, the value of p at equilibrium is determined by nature. Similarly, if p and T are chosen arbitrarily, then the value of V at equilibrium is fixed. That is, of the three thermodynamic coordinates p, V, and T, only two are independent variables. This implies that there exists an equation of equilibrium which connects the thermodynamic coordinates and which robs one of them of its independence. ⑫ Such an equation, called an equation of state, is a mathematical function relating the appropriate thermodynamic coordinates of a system in equilibrium. Every thermodynamic system has its own equation of state, although in some cases the relation may be so complicated that it cannot be expressed in terms of simple mathematical functions. For a closed system, the equation of state re-

lates the temperature to two other thermodynamic variables.

An equation of state expresses the individual peculiarities of one system as compared with another system and must, therefore, be determined either by experiment or by molecular theory. A general theory like thermodynamics, based on general laws of nature, is incapable of generating an equation of state of any system. An equation of state, therefore, is not a theoretical deduction from thermodynamics, but is usually an experimental addition to thermodynamics. It expresses the results of experiments in which the thermodynamic coordinates of a system were measured as accurately as possible, within a limited range of values. An equation of state is, therefore, only as accurate as the experiments that led to its formulation, and holds only within the range of values measured. As soon as this range is exceeded, a different form of equation of state may be valid.

For example, a system consisting of a gas at very low pressure has the simple equation of state of an ideal gas,

$$PV = nRT$$

where n is the number of moles and R is the molar gas constant. Equation $PV = nRT$ is often rewritten as

$$Pv = RT$$

where lower-case v indicates the molar volume, that is, volume V per mole n. At higher pressures, the equation of state is more complicated, being fairly well represented by the van der Waals equation, which takes into account particle interactions and the finite size of the particles. [13] Thus,

$$\left(P + \frac{a}{v^2}\right)(v - b) = RT$$

Where a and b are constants appropriate to the specific gas. As far as thermodynamics is concerned, the important idea is that an equation of state exists, not whether we can write it down in simple mathematical form.

Mathematical Formulation of the First Law. We give the following as our thermodynamic definition of heat: When a closed system whose surroundings are at a different temperature and on which diathermic work may be done undergoes a process, then the energy transferred by nonmechanical means, equal to the difference between the change of internal energy and the diathermic work, is called heat. Denoting heat by Q, we have

$$Q = (U_f - U_i) - W$$

or

$$U_f - U_i = Q + W$$

Where the sign convention has been adopted that Q is positive when it enters a system and negative when it leaves a system. U_i and U_f represent the internal energy at initial and final state. Like internal energy and work, heat is measured in joules in the SI system. Equation $U_f - U_i = Q + W$ is known as the mathematical formulation of the first law of thermodynamics.

Carnot's Theorem. Carnot's theorem is stated as follows: No heat engine operating between two given reservoirs can be more efficient than a Carnot engine operating between the same two reservoirs.

(From *Heat and Thermodynamics* by M. W. Zemansky and R. H. Dittman)

难句释义

① 全句译为：时间是事件先后顺序的量度。

② this property 等同于 mass；manifest 意为“使显现”；“resistance of matter to a change in velocity”直译为“物体抵抗速度变化的能力”，即“惯性”的含义。全句译为：质量使两个物体之间产生万有引力，并是物体惯性大小的量度。

③ 全句译为：在任何情况下，力的大小、方向和作用点这三个要素都可以完整地描述一个力。

④ 主句为“A rigid body can be considered as a combination of a large number of particles”；which 为关系代词，指代“A rigid body”；“before and after applying a load”为分词结构充当状语，修饰定语从句；particle 表示“质点”；fixed 意为“固定的，不变的”。全句译为：刚体可以看作是大量质点的集合。在刚体中，所有质点之间的距离始终保持不变，与刚体是否受力无关。

⑤“we”可以省略不译，“provided”之后是假设的情况。全句译为：载荷可以集中力表示，即假设载荷作用的面积与物体的表面积相比非常小。

⑥“the surface at the points of contact”即为“接触面”；全句译为：这个力的作用总是与接触面相切，其方向与两个接触面相对运动或相对运动趋势的方向相反。

⑦ desirable 意为“理想的，良好的”。全句译为：模型研究的理想特征之一就是几何相似，也就是说模型和实型具有相同的形状，只有尺寸不同。

⑧ in addition to 是介词短语，意为“除了”。全句译为：如果两个系统除了运动相似外，对应部位受力都成同一比例，则它们就动力相似。

⑨ a surface 是指绕流固体的表面，we 在翻译时可省略，which 引导的定语从句可以与主句拆译。全句译为：边界层是最靠近固体表面的流体薄层。在边界层中，黏性力起主导作用；而在边界层外的流体可以看作是无摩擦或理想流体。

⑩“a tube with a constricted throat”其实说明两部分结构，即收缩管和喉部；“followed by a gradually diverging portion”又说明了第三部分结构；因此文丘里管由三部分组成。全句译为：它由渐缩管、喉部和渐扩管组成。在渐缩段和喉部由于速度逐渐增大而引起压强降低；而在渐扩管内，速度又转化为压强，但是会产生少量摩擦损失。

⑪ 全句译为：热力循环由系统与环境做功的热力过程或二者传热的热力过程组成，环境包括一个高温热源和一个低温热源。

⑫“robs one of them of its independence”直译为“剥夺了它们其中之一的独立性”，理解其含义，可意译为“三个坐标中两个是独立的”。全句译为：这就说明存在一个平衡方程可以将这三个热力学坐标联系起来，使得其中两个是独立的。

⑬ 句中存在一个现在分词结构和一个定语从句。全句译为：在高压情况下，状态方程的形式更加复杂，可以用 van der Waals 方程描述，考虑了气体分子之间的相互作用及分子的体积的影响。

Unit 6

Design of Machinery

6.1 The Design Process

The design engineer, in practice, regardless of discipline, continuously faces the challenge of structuring the unstructured problem. Inevitably, the problem as posed to the engineer is ill-defined and incomplete. Before any attempt can be made to analyze the situation he or she must first carefully define the problem, using an engineering approach, to ensure that any proposed solution will solve the right problem. Many examples exist of excellent engineering solutions which were ultimately rejected because they solved the wrong problem, i. e. , a different one than the client really had.

Much research has been devoted to the definition of various "design processes" intended to provide means to structure the unstructured problem and lead to a viable solution. Some of these processes present dozens of steps, others only a few. The one presented below contains 10 steps and has proven successful in over 30 years of practice in engineering design.

Step One: Identification of Need

This first step is often done for you by someone, boss or client, saying "What we need is. . . " Typically this statement will be brief and lacking in detail. It will fall far short of providing you with a structured problem statement. [1]

Step Two: Background Research

This is the most important phase in the process, and is unfortunately often the most neglected. The term research is a moremundane sort, gathering background information on the relevant physics, chemistry, or other aspects of the problem. Also it is desirable to find out if this, or a similar problem, has been solved before. There is no point in reinventing the wheel. If you are lucky enough to find a ready-made solution on the market, it will no doubt be more economical to purchase it than to build your own. Most likely this will not be the case, but you may learn a great deal about the problem to be solved by investigating the existing "art" associated with similar technologies and products. The patent literature and technical publications in the subject area are obvious sources of information and are accessible via the worldwide web. Clearly, if you find that the solution exists and is covered by a patent still in force, you have only a few ethical choices: buy the patentee's existing solution, design something which does not conflict with the patent, or drop the project. It is very important that sufficient energy and time be expended on this research and preparation phase of the

process in order to avoid the embarrassment of concocting a great solution to the wrong problem. Most inexperienced (and some experienced) engineers give too little attention to this phase and jump too quickly into the ideation and invention stage of the process. This must be avoided! You must discipline yourself to not try to solve the problem before thoroughly preparing yourself to do so.

Step Three: Goal Statement

Once the background of the problem area as originally stated is fully understood, you will be ready to recast that problem into a more coherent goal statement. This new problem statement should have three characteristics. It should be concise, be general, and be uncolored by any terms which predict a solution. It should be couched in terms of functional visualization, meaning to visualize its function, rather than any particular embodiment. For the ideation phase to be most successful, it is necessary to avoid such images and to state the problem generally, clearly, and concisely. You should use functional visualization to avoid unnecessarily limiting your creativity!

Step Four: Performance Specifications

When the background is understood, and the goal clearly stated, you are ready to formulate a set of performance specifications. These should not be design specifications. The difference is that performance specifications define what the system must do, while design specifications define how it must do it. At this stage of the design process it is unwise to attempt to specify how the goal is to be accomplished. That is left for the ideation phase. The purpose of the performance specifications is to carefully define and constrain the problem so that it both can be solved and can be shown to have been solved after the fact.

Step Five: Ideation and Invention

This step is full of both fun and frustration. This phase is potentially the most satisfying to most designers, but it is also the most difficult. A great deal of research has been done to explore the phenomenon of "creativity". It is, most agree, a common human trait. Some claim that creativity can be taught, some that it is only inherited. No hard evidence exists for either theory. It is probably true that one's lose or suppressed creativity can be rekindled. Other studies suggest that most everyone underutilizes his or her potential creative abilities. You can enhance your creativity through various techniques.

Step Six: Analysis

Once you are at this stage, you have structured the problem, at least temporarily, and can apply more sophisticated analysis techniques to examine the performance of the design in the analysis phase of the design process. Further iteration will be required as problems are discovered from the analysis. Repetition of as many earlier steps in the design process as necessary must be done to ensure the success of the design.

Step Seven: Selection

When the technical analysis indicates that you have some potentially viable designs, the best one available must be selected for detailed design, prototyping, and testing. The selection process usually involves a comparative analysis of the available design solutions. A decision matrix sometimes helps to identify the best solution by forcing you to consider a variety of factors in a systematic way. A

decision matrix for a better grass shortener is shown in Table 6-1. Each design occupies a row in the matrix. The columns are assigned categories in which the designs are to be judged, such as cost, ease of use, efficiency, performance, reliability, and any others you deem appropriate to the particular problem. Each category is then assigned a weighting factor, which measures its relative importance. For example, reliability may be a more important criterion to the user than cost, or vice versa. You as the design engineer have to exercise your judgment as to the selection and weighting of these categories. The body of the matrix is then filled with numbers which rank each design on a convenient scale, such as 1 to 10, in each of the categories. Note that this is ultimately a subjective ranking on your part. You must examine the designs and decide on a score for each. The scores are then multiplied by the weighting factors (which are usually chosen so as to sum to a convenient number such as 1) and the products summed for each design. The weighted scores then give a ranking of designs. Be cautious in applying these results. Remember the source and subjectivity of your scolds and the weighting factors! There is a temptation to put more faith in these results than is justified. After all, they look impressive! They can even be taken out to several decimal places! (But they shouldn't be.) The real value of a decision matrix is that it breaks the problem into more tractable pieces and forces you to think about the relative value of each design in many categories. You can then make a more informed decision as to the "best" design.

Table 6-1 A decision matrix

	Cost	Safety	Performance	Reliability	Rank
Weighting Factor	0.35	0.30	0.15	0.20	1.0
Design 1	3 / 1.05	6 / 1.80	4 / 0.60	9 / 1.80	5.3
Design 2	4 / 1.40	2 / 0.60	7 / 1.05	2 / 0.40	3.5
Design 3	1 / 0.35	9 / 2.70	4 / 0.60	5 / 1.00	4.7
Design 4	9 / 3.15	1 / 0.30	6 / 0.90	7 / 1.40	5.8
Design 5	7 / 2.45	4 / 1.20	2 / 0.30	6 / 1.20	5.2

Step Eight: Detailed Design

This step usually includes the creation of a complete set of assembly and detail drawings or Computer-Aided Design (CAD) part files, for each and every part used in the design. Each detail drawing must specify all the dimensions and the material specifications necessary to make that part. From these drawings (or CAD files) a prototype test model (or models) must be constructed for physical testing. Most likely the tests will discover more flaws, requiring further iteration.

Step Nine: Prototyping and Testing

(1) Models. Ultimately, one cannot be sure of the correctness or viability of any design until it is built and tested. This usually involves the construction of a prototype physical model. A mathematical model, while very useful, can never be as complete and accurate a representation of the actual physical system as a physical model, due to the need to make simplifying assumptions. Prototypes are often very expensive but may be the most economical way to prove a design, short of building the actual, full-scale device. ② Prototypes can take many forms, from working scale models to full-size, but simplified, representations of the concept. Scale models introduce their own complications in regard to proper scaling of the physical parameters. For example, volume of material varies as the cube of linear dimensions, but surface area varies as the square. Heat transfer to the environment may be proportional to surface area, while heat generation may be proportional to volume. So linear scaling of a system, either up or down, may lead to behavior different from that of the full-scale system. One must exercise caution in scaling physical models. You will find as you begin to design linkage mechanisms that a simple cardboard model of your chosen link lengths, coupled together with thumbtacks for pivots, will tell you a great deal about the quality and character of the mechanism's motions. You should get into the habit of making such simple articulated models for all your linkage designs.

(2) Testing. Testing of the model or prototype may range from simply actuating it and observing its function to attaching extensive instrumentation to accurately measure displacements, velocities, accelerations, forces, temperatures, and other parameters. Tests may need to be under controlled environmental conditions such as high or low temperature or humidity. The microcomputer has made it possible to measure many phenomena more accurately and inexpensively than could be done before.

Step Ten: Production

Finally, with enough time, money, and perseverance, the design will be ready for production. This might consist of the manufacture of a single final version of the design, but more likely will mean making thousands or even millions of your widget. The danger, expense, and embarrassment of finding flaws in your design after making large quantities of defective devices should inspire you to use the greatest care in earlier steps of the design process to ensure that it is properly engineered.

It is necessary to point out that above design process is not a process in which one proceeds from step one through ten in a linear fashion. Rather it is, by its nature, an iterative process in which progress is made haltingly, two steps forward and one step back. It is inherently circular. To iterate means to repeat, to return to a previous state. If, for example, your apparently great idea, upon analysis, turns out to violate the second law of thermodynamics, you can return to the ideation step and get a better idea. Or, if necessary, you can return to an earlier step in the process, perhaps the background research, and learn more about the problem.

6.2 Kinematic Fundamentals

At the beginning, the definition of the kinematic chain, mechanism, and machine based on

Reuleaux's classifications will be first given.

1. Kinematic Chain

A kinematic chain is defined as: an assemblage of links and joints, interconnected in a way to provide a controlled output motion in response to a supplied input motion.

2. Mechanism

A mechanism is defined as: a kinematic chain in which at least one link has been "grounded", or attached, to the frame of reference (which itself may be in motion).

3. Machine

Amachine is defined as: a combination of resistant bodies arranged to compel the mechanical forces of nature to do work accompanied by determinate motions. ③

6.2.1 Degrees of Freedom

Any mechanical system can be classified according to the number of degrees of freedom (DOF) which it possesses. The system's DOF is equal to the number of independent parameters (measurements) which are needed to uniquely define its position in space at any instant of time. Note that DOF is defined with respect to a selected frame of reference. The concept of DOF is fundamental to both the synthesis and analysis of mechanisms. We need to be able to quickly determine the DOF of any collection of links and joints which may be suggested as a solution to a problem. DOF (also called the mobility M) of a system can be defined as: DOF is the number of inputs which need to be provided in order to create a predictable output or the number of independent coordinates required to define its position.

Kinematic chains or mechanisms may be either open or closed. A closed mechanism will have no open attachment points or nodes and may have one or more DOF. An open mechanism of more than one link will always have more than one DOF, thus requiring as many actuators (motors) as it has DOF. A common example of an open mechanism is an industrial robot. An open kinematic chain of two binary links and one joint is called a dyad.

1. DOF in Planar Mechanisms

To determine the overall DOF of any mechanism, we must account for the number of links and joints, and for the interactions among them. The DOF of any assembly of links can be predicted from an investigation of the Gruebler condition. Any link in a plane has 3 DOF. Therefore, a system of n unconnected links in the same plane will have $3n$ DOF. For example, two unconnected links have a total of six DOF as shown in Figure 6-1a. When these links are connected by a full joint in Figure 6-1b, Δy_1 and Δy_2 are combined as Δy, and Δx_1 and Δx_2 are combined as Δx. This removes two DOF, leaving four DOF. In Figure 6-1c the half joint removes only one DOF from the system (because a half joint has two DOF), leaving the system of two links connected by a half joint with a total of five DOF. In addition, when any link is grounded or attached to the reference frame, all three of its DOF will be removed. This reasoning leads to Gruebler's equation:

$$M = 3n - 2J - 3G \tag{6-1}$$

where M = degree of freedom or mobility

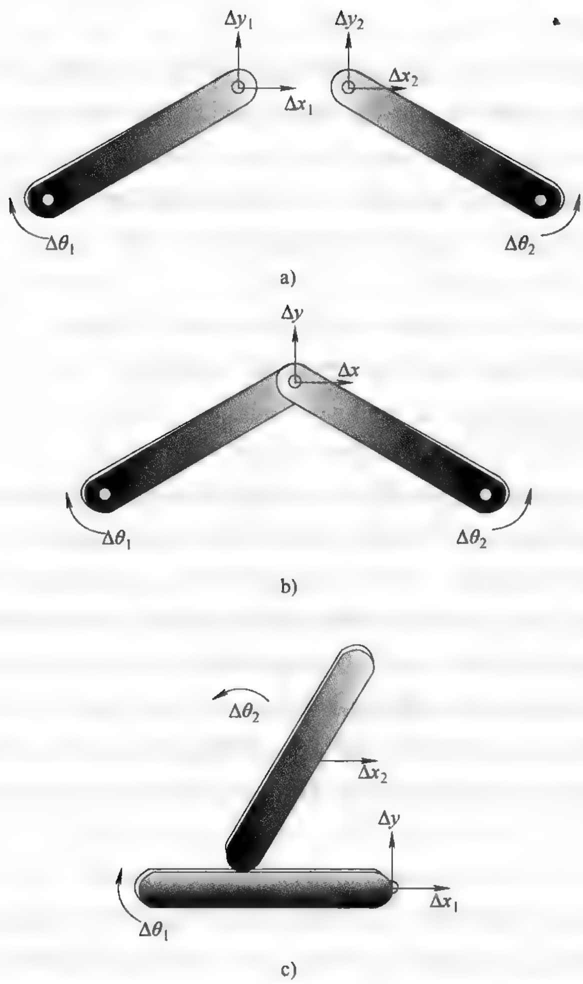


Figure 6-1 DOF of two links

a) Two unconnected links, DOF = 6 b) Connected by a full joint, DOF = 4 c) Connected by a roll-slide (half) joint, DOF = 5

n = number of links

J = number of joints

G = number of grounded links

2. Degree of Freedom in Spatial Mechanisms

The approach used to determine the mobility of a planar mechanism can be easily tended to three dimensions. Each unconnected link in three-space has 6 DOF, and any one of the six lower pairs can be used to connect them, as can higher pairs with more freedom. A one-freedom joint removes 5 DOF, a two-freedom joint removes 4 DOF, etc. Grounding a link removes 6 DOF. This leads to the Kutzbach mobility equation for spatial linkages:

$$M = 6(n-1) - 5J_1 - 4J_2 - 3J_3 - 2J_4 - J_5 \tag{6-2}$$

where the subscript refers to the number of freedoms of the joint.

6.2.2 Motions and Linkages

1. Type of Motion

A rigid body free to move within a reference frame will, in the general case, have complex motion, which is a simultaneous combination of rotation and translation. In a plane, or two-dimensional space, complex motion becomes a combination of simultaneous rotation about one axis (perpendicular to the plane) and also translation resolved into components along two axes in the plane.

(1) Pure rotation. The body possesses one point (center of rotation) which has no motion with respect to the "stationary" frame of reference. All other points on the body describe arcs about that center. A reference line drawn on the body through the center changes only its angular orientation.

(2) Pure translation. All points on the body describe parallel (curvilinear or rectilinear) paths. A reference line drawn on the body changes its linear position but does not change its angular orientation.

(3) Complex motion. A simultaneous combination of rotation and translation. Any reference line drawn on the body will change both its linear position and its angular orientation. Points on the body will travel nonparallel paths, and there will be, at every instant, a center of rotation, which will continuously change location.

2. Links, Joints and Kinematic Pairs

We will begin our exploration of the kinematics of mechanisms with an investigation of the subject of linkage design. Linkages are the basic building blocks of all mechanisms. All common forms of mechanisms (cams, gears, belts, chains) are in fact variations of a common theme of linkages. Linkages are made up of links and joints.

(1) Link. A link, is an (assumed) rigid body which possesses at least two nodes which are points for attachment to other links. Binary link has two nodes, ternary link has three nodes, and quaternary link has four nodes.

(2) Joint. A joint (also called kinematic pairs) is a connection between two or more links (at their nodes), which allows some motion, or potential motion, between the connected links.

Reuleaux coined the term lower pair to describe joints with surface contact (as with a pin surrounded by a hole) and the term higher pair to describe joints with point or line contact. The main practical advantage of lower pairs over higher pairs is their better ability to trap lubricant between their enveloping surfaces. This is especially true for the rotating pin joint. The lubricant is more easily squeezed out of a higher pair, non-enveloping joint. As a result, the pin joint is preferred for low wear and long life, even over its lower pair cousin, the prismatic or slider joint. The revolute and the prismatic pairs are the only lower pairs usable in a planar mechanism. The screw, cylindrical, spherical, and flat lower pairs are all combinations of the revolute and/or prismatic pairs and are used in spatial (3-D) mechanisms.

A more useful means to classify joints (pairs) is by the number of degrees of freedom that they allow between the two elements joined. The rotating pin joint and translating slider joint are two forms of planar, one-freedom joint (or pair), which are also referred to as full joints (i. e., full = 1

DOF) and are lower pairs. The pin joint allows one rotational DOF, and the slider joint allows one translational DOF between the joined links. These are both contained withtn (and each is a limiting case of) another common, one-freedom joint, the screw and nut. Motion of either the nut or the screw with respect to the other results in helical motion. If the helix angle is made zero, the nut rotates without advancing and it becomes the pin joint. If the helix angle is made 90 degrees, the nut will translate along the axis of the screw, and it becomes the slider joint.

Two-freedom joints (higher pairs) simultaneously allow two independent, relative motions, namely translation and rotation, between the joined links. Paradoxically, this two-freedom joint is sometimes referred to as a "half joint", with its two freedoms placed in the denominator. The half joint is also called a roll-slide joint because it allows both rolling and sliding. A spherical, or ball-and-socket joint, is an example of a three-freedom joint, which allows three independent angular motions between the two links joined. This ball joint would typically be used in a three-dimensional mechanism, one example being the ball joints in an automotive suspension system.

3. Linkage Transformation

The number synthesis techniques give the designer a toolkit of basic linkages of particular DOF. If we now relax the arbitrary constraint which restricted us to only revolute joints, we can transform these basic linkages to a wider variety of mechanisms with even greater usefulness. There are several transformation techniques or rules that we can apply to planar kinematic chains.

1) Revolute joints in any loop can be replaced by prismatic joints with no change in DOF of the mechanism, provided that at least two revolute joints remain in the loop.

2) Any full joint can be replaced by a half joint, but this will increase the DOF by one.

3) Removal of a link will reduce the DOF by one.

4) The combination of rules 2 and 3 above will keep the original DOF unchanged.

5) Any ternary or higher-order link can be partially "shrunk" to a lower-order link by coalescing nodes. This will create a multiple joint but will not change the DOF of the mechanism.

6) Complete shrinkage of a higher-order link is equivalent to its removal. A multiple joint will be created, and the DOF will be reduced.

4. Intermittent Motion

Intermittent motion is a sequence of motions and dwells. A dwell is a period in which the output link remains stationary while the input link continues to move. There are many applications in machinery which require intermittent motion. The cam-follower variation on the four-bar linkage is often used in these situations.

1) Geneva mechanism. Common form of intermittent motion device is the Geneva mechanism shown in Figure 6-2a. It is also a transformed four-bar linkage in which the coupler has been replaced by a half joint. The input crank is typically motor driven at a constant speed. The Geneva wheel is fitted with at least three equispaced, radial slots. The crank has a pin that enters a radial slot and causes the Geneva wheel to turn through a portion of a revolution. When the pin leaves that slot, the Geneva wheel remains stationary until the pin enters the next slot. The result is intermittent rotation of the Geneva wheel.

The crank is also fitted with an arc segment, which engages a matching cutout on the periphery of the Geneva wheel when the pin is out of the slot. ④ This keeps the Geneva wheel stationary and in the proper location for the next entry of the pin. The number of slots determines the number of "stops" of the mechanism, where stop is synonymous with dwell. A Geneva wheel needs a minimum of three stops to work. The maximum number of stops is limited only by the size of the wheel.

2) Ratchet and pawl mechanism. In a ratchet and pawl mechanism shown in Figure 6-2b, the arm pivots about the center of the toothed ratchet wheel and is moved back and forth to index the wheel. The driving pawl rotates the ratchet wheel (or ratchet) in the counterclockwise direction and does no work on the return (clockwise) trip. The locking pawl prevents the ratchet from reversing direction while the driving pawl returns. Both pawls are usually spring-loaded against the ratchet. This mechanism is widely used in devices such as "ratchet" wrenches, winches, etc.

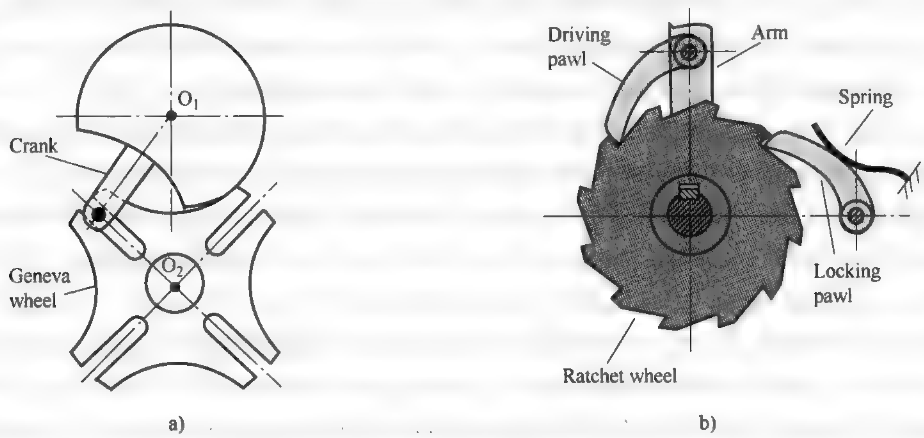


Figure 6-2 Common forms of intermittent motion device
a) Geneva mechanism b) Ratchet and pawl mechanism

5. Inversion

It should now be apparent that there are many possible linkages for any situation. In addition, we can introduce another factor, namely mechanism inversion. An inversion is created by grounding a different link in the kinematic chain. Thus there are as many inversions of a given linkage as it has links. The motions resulting from each inversion can be quite different, but some inversions of a linkage may yield motions similar to other inversions of the same linkage. In these cases only some of the inversions may have distinctly different motions. We will denote the inversions which have distinctly different motions as distinct inversions.

6.3 Practical Design Considerations of Cam

Cam-follower systems can be classified in several ways: by type of follower motion, either translating or rotating (oscillating); by type of cam, radial, cylindrical, three-dimensional; by type of joint closure, either force- or form-closed; by type of follower, curved or flat, rolling or sliding; by

type of motion constraints, critical extreme position (CEP), critical path motion (CPM); by type of motion program, rise-fall (RF), fall-dwell (RFD), rise-dwell-fall-dwell (RDFD). ⑤ Therefore, the cam designer is often faced with many confusing decisions, especially at an early stage of the design process. Many early decisions, often made somewhat arbitrarily and without much thought, can have significant and costly consequences later in the design. The following is a discussion of some of the trade-offs involved with such decisions in the hope that it will provide the cam designer with some guidance in making these decisions.

1. Translating or Oscillating Follower

There are many cases, especially early in a design, when either translating or rotating motion could be accommodated as output from the cam. Approximate straight-line motion is often adequate and can be obtained from a large-radius rocker follower. The rocker or oscillating follower has one significant advantage over the translating follower when a roller follower is used. A translating follower is free to rotate about its axis of translation and may need to have some anti-rotation guiding (such as a keyway) provided to prevent misalignment of a roller follower with the cam.

Conversely, the oscillating follower will keep the roller follower aligned in the same plane as the cam with no guiding beyond its own pivot. Also, the pivot friction in an oscillating follower typically has a small moment arm compared to the moment of the force from the cam on the follower arm. But, the friction force on a translating follower has a one-to-one geometric relationship with the cam force. This can have a larger parasitic effect on the system.

On the other hand, translating flat-faced followers are often deliberately arranged with their axis slightly out of the plane of the cam in order to create a rotation about their own axis due to the frictional moment resulting from the offset. The flat follower will then precess around its own axis and distribute the wear over its entire face surface. This is common practice in automotive valve cams that use flat-faced followers or "tappets".

2. Force or Form-Closed

A form-closed (track or groove) cam is more expensive to make than a force-closed (open) cam simply because there are two surfaces to machine and grind. Also, heat treating will often distort the track of a form-closed cam, narrowing or widening it such that the roller follower will not fit properly. This virtually requires post heat-treat grinding for track cams in order to resize the slot. An open (force-closed) cam will also distort on heat-treating but may still be usable without grinding.

The principal advantage of a form-closed (track) cam is that it does not need a return spring, and thus can be run at higher speeds than a force-closed cam whose spring and follower mass will go into resonance at some speed, causing potentially destructive follower jump. High-speed automobile and motorcycle racing engines often use form-closed (desmodromic) valve cam trains to allow higher engine rpm without incurring valve "float", or follower jump.

Though the lack of a return spring can be an advantage, it comes, as usual, with a trade-off. In a form-closed (track) cam there will be crossover shock each time the acceleration changes sign. Crossover shock describes the impact force that occurs when the follower suddenly jumps from one side of the track to the other as the dynamic force reverses sign. There is no flexible spring in this

system to absorb the force reversal as in the force-closed case. The high impact forces at crossover cause noise, high stresses, and local wean. Also, the roller follower has to reverse direction at each crossover which causes sliding and accelerates follower wear. Studies have shown that roller followers running against a well-lubricated open radial cam have slip rates of less than 1%.

3. Radial or Axial Cam

This choice is largely dictated by the overall geometry of the machine for which the cam is being designed. If the follower must move parallel to the camshaft axis, then an axial cam is dictated. If there is no such constraint, a radial cam is probably a better simply because it is a less complicated, thus cheaper cam to manufacture.

4. Roller or Flat-Faced Follower

The roller follower is a better choice from a cam design standpoint simply because it accepts negative radius of curvature on the cam. This allows more variety in the cam program. Also, for any production quantities, the roller follower has the advantage of being available from several manufacturers in any quantity from one to a million. For low quantities it is not usually economical to design and build your own custom follower. In addition, replacement roller followers can be obtained from suppliers on short notice when repairs are needed. Also, they are not particularly expensive even in small quantities.

Perhaps the largest users of flat-faced followers are automobile engine makers. Their quantities are high enough to allow any custom design they desire. ⑥ It can be made or purchased economically in large quantity and can be less expensive than a roller follower in that case. Also with engine valve cams, a flat follower can save space over a roller. However, many manufacturers have switched to roller followers in automobile engines to reduce friction and improve fuel mileage. Diesel engines have long used roller followers (tappets) as have racers who "hop-up" engines for high performance. ⑦

Cams used in automated production line machinery use stock roller followers almost exclusively. The ability to quickly change a worn follower for a new one taken from the stockroom without losing much production time on the "line" is a strong argument in this environment. Roller followers come in several varieties. They are based on roller or ball bearings. Plain bearing versions are also available for low-noise requirements. The outer surface, which rolls against the cam can be either cylindrical or spherical in shape. The "crown" on the spherical follower is slight, but it guarantees that the follower will ride near the center of a flat cam regardless of the accuracy of alignment of the axes of rotation of cam and follower. If a cylindrical follower is chosen and care is not taken to align the axes of cam and roller follower, the follower will ride on one edge and wear rapidly.

Commercial roller followers are typically made of high carbon alloy steel such as AISI 52100 and hardened to Rockwell 60 – 62HRC. The 52100 alloy is well suited to thin sections that must be heat-treated to a uniform hardness. Because the roller makes many revolutions for each cam rotation, its wear rate may be higher than that of the cam. Chrome plating the follower can markedly improve its life. Chrome is harder than steel at about 70HRC. Steel cams are typically hardened to a range of 50 – 55HRC.

5. To Dwell or Not to Dwell

The need for a dwell is usually clear from the problem specifications. If the follower must be held stationary for any time, then a dwell is required. Some cam designers tend to insert dwells in situations where they are not specifically needed for follower stasis, in a mistaken belief that this is preferable to providing a rise-return motion when that is what is really needed. If the designer is attempting to use a double-dwell program in a single-dwell case, then perhaps his or her motivation to "let the vibrations settle out" by providing a "short dwell" at the end of the motion is justified. However, he or she probably should be using another cam program, perhaps a polynomial tailored to the specifications. Taking the acceleration to zero, whether for an instant or for a "short dwell" is generally unnecessary and undesirable. A dwell should be used only when the follower is required to be stationary for some measurable time. Moreover, if you do not need any dwell at all, consider using a linkage instead. They are a lot easier and cheaper to manufacture.

6. To Grind or Not to Grind

Many production machinery cams are used as-milled, and not ground. Automotive valve cams are ground. The reasons are largely due to cost and quantity considerations as well as the high speeds of automotive cams. There is no question that a ground cam is superior to a milled cam. The question in each case is whether the advantage gained is worth the cost. In small quantities, as are typical of production machinery, grinding about doubles the cost of a cam. The advantages in terms of smoothness and quietness of operation, and of wear, are not in the same ratio as the cost difference. A well-machined cam can perform nearly as well as a well-ground cam and better than a poorly ground cam.

Automotive cams are made in large quantity, run at very high speed, and are expected to last for a very long time with minimal maintenance. This is a very challenging specification. It is a great credit to the engineering of these cams that they very seldom fail in 100, 000 miles or more of operation. These cams are made on specialized equipment which keeps the cost of their grinding to a minimum.

7. To Lubricate or Not to Lubricate

Cams need lots of lubrication. Automotive cams are literally drowned in a flow of engine oil. Many production machine cams run immersed in an oil bath. These are reasonably happy cams. Others are not so fortunate. Cams which operate in close proximity to the product on an assembly machine in which oil would cause contamination of the product (food products, personal products) often are run dry. Camera mechanisms, which are full of linkages and cams, are often run dry. Lubricant would eventually find its way to the film.

Unless there is some good reason to eschew lubrication, a cam-follower should be provided with a generous supply of clean lubricant, preferably a hypoid-type oil containing additives for boundary lubrication conditions. The geometry of a cam-follower join (half-joint) is among the worst, possible from a lubrication standpoint. Unlike a journal bearing, which tends to trap a film of lubricant within the joint, the half joint is continually trying to squeeze the lubricant out of itself. This can result in a boundary, or mixed boundary/EHD lubrication state in which some metal-to-metal contact will occur. Lubricant must be continually resupplied to the joint. Another purpose of the liquid lubricant is

to remove the heat of friction from the joint. If run dry, significantly higher material temperatures will result, with accelerated wear and possible early failure.

6.4 Gear Trains

1. Simple Gear Train and Compound Gear Train

A gear train is any collection of two or more meshing gears. A simple gear train is one in which each shaft carries only one gear. A single gear set of spur, helical, or bevel gears is usually limited to a ratio of about 10: 1 simply because the gear set will become very large, expensive, and hard to package above that ratio if the pinion is kept above the minimum numbers of teeth to avoid interference between a full-depth pinion and a full-depth rock.

To get a train radio of greater than about 10: 1 with spur, helical, or bevel gears (or any combination thereof) it is necessary to compound the train (unless an epicyclic train is used). A compound train is one in which at least one shaft carries more than one gear. This will be a parallel or series-parallel arrangement, rather than the pure series connections of the simple gear train.

2. Epicyclic or Planetary Gear Trains

The conventional gear trains described in the previous sections are all one degree-of-freedom (DOF) devices. Another class of gear train has wide application, the epicyclic or planetary train. This is a two-DOF device. Two inputs are needed to obtain a predictable output.

Most planetary trains will be arranged with ring gears to bring the planetary motion back to a grounded pivot. Note how the sun gear, ring gear, and arm are all brought out as concentric hollow shafts so that each can be accessed to tap its angular velocity and torque either as an input or an output. It is very difficult to determine the behavior of a planetary train by observation. We must do the necessary calculations to determine its behavior and may be surprised at the often counterintuitive results.

3. Efficiency of Gear Trains

The general definition of efficiency is output power/input power. It is expressed asa fraction (decimal %) or as a percentage. The efficiency of a conventional gear train (simple or compound) is very high. The power loss per gear set is only about 1% to 2% depending on such factors as tooth finish and lubrication. A gear set's basic efficiency is termed E_0. An external gear set will have an E_0 of about 0.98 or better and an external-internal gear set about 0.99 or better. When multiple gear sets are used in a conventional simple or compound train, the overall efficiency of the train will be the product of the efficiencies of its stages. For example, a two-stage train with both gear set efficiencies of $E_0 = 0.98$ will have an overall efficiency of $\eta = 0.98^2 = 0.96$.

Epicyclic trains, if properly designed, can have even higher overall efficiencies than conventional trains. But, if the epicyclic train is poorly designed, its efficiency can be so low that it will generate excessive heat and may even be unable to operate at all.

6.5 Dynamiçs Fundamentals

This part will address the problem of determining the forces present in moving mechanisms and

machinery. This topic is called kinetics or dynamic force analysis.

1. Newton's Laws of Motion

Dynamic force analysis involves the application of Newton's three laws of motion which are illustrated in the Unit 5.

2. Dynamic Models

It is often convenient in dynamic analysis to create a simplified model of a complicated-part. These models are sometimes considered to be a collection of point masses connected by massless rods. For a model of a rigid body to be dynamically equivalent to the original body, three things must be true:

1) The mass of the model must equal that of the original.

2) The center of gravity must be in the same location as that of the original body.

3) The mass moment of inertia must equal that of the original body.

3. Mass of a Rigid Body

Mass is an invariant property of a rigid body. The weight same body varies depending on the gravitational system in which it sits. We will assume the mass of the parts to be constant in calculations. For most earthbound machinery, this is a reasonable assumption.

Unlike a static force situation in which a failed design might be fixed by adding more mass to the part to strengthen it, to do so in a dynamic force situation can have a deleterious effect. More mass with the same acceleration will generate even higher forces and thus higher stresses. The machine designer often needs to remove mass (in the right places) from parts in order to reduce the stresses and deflections due to $\boldsymbol{F} = m\boldsymbol{a}$. Thus the designer needs to have a good understanding of both material properties and stress and deflection analysis to properly shape and size parts for minimum mass while maximizing the strength and stiffness needed to withstand the dynamic forces.

4. Mass Moment and Center of Gravity

When the mass of an object is distributed over some dimensions, it will possess a moment with respect to any axis of choice. Figure 6-3 shows a mass of general shape in an $X\ Y\ Z$ axis system. A differential element of mass is also shown. The mass moment (first moment of mass) of the differential element is equal to the product of its mass and its distance from the axis of interest. With respect to the X, Y, and Z axes these are

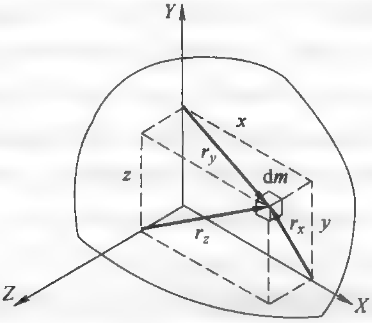


Figure 6-3 A generalized mass in a 3-D coordinate system

$$dM_x = r_x^1 dm = \sqrt{(y^2 + z^2)}\,dm \tag{6-3a}$$
$$dM_y = r_y^1 dm = \sqrt{(x^2 + z^2)}\,dm \tag{6-3b}$$
$$dM_z = r_z^1 dm = \sqrt{(x^2 + y^2)}\,dm \tag{6-3c}$$

The radius from the axis of interest to the differential element is shown with an exponent of 1 to emphasize the reason for this property being called the first moment of mass (一阶质量矩). To obtain the mass moment of the entire body we integrate each of these expression.

$$M_x = \int \sqrt{(y^2 + z^2)}\,dm \tag{6-4a}$$
$$M_y = \int \sqrt{(x^2 + z^2)}\,dm \tag{6-4b}$$
$$M_z = \int \sqrt{(x^2 + y^2)}\,dm \tag{6-4c}$$

If the mass moment with respect to a particular axis is numerically zero, then that axis passes through the center of mass (CM) of the object, which for earthbound systems is coincident with its center of gravity (CG).

5. Mass Moment of Inertia (Second Moment of Mass)

Newton's law applies to systems in rotation as well as to those in translation. The rotational form of Newton's second law is

$$\boldsymbol{T} = I\boldsymbol{\alpha} \tag{6-5}$$

Where $\boldsymbol{T}$ is resultant torque about the mass center, $\boldsymbol{\alpha}$ is angular acceleration, and I is mass moment of inertia about an axis through the mass center.

The mass moment of inertia of the, differential element is equal to the product of its mass and the square of its distance from the axis of interest. With respect to the X, Y, and Z axes they are

$$dI_x = r_x^2 dm = (y^2 + z^2)\,dm \tag{6-6a}$$
$$dI_y = r_y^2 dm = (x^2 + z^2)\,dm \tag{6-6b}$$
$$dI_z = r_z^2 dm = (x^2 + y^2)\,dm \tag{6-6c}$$

The exponent of 2 on the radius term gives this property its other name of second moment of mass. To obtain the mass moments of inertia of the entire body we integrate each of these expressions.

$$I_x = \int (y^2 + z^2)\,dm \tag{6-7a}$$
$$I_y = \int (x^2 + z^2)\,dm \tag{6-7b}$$
$$I_z = \int (x^2 + y^2)\,dm \tag{6-7c}$$

In a translating system kinetic energy is

$$KE = \frac{1}{2}mv^2 \tag{6-8a}$$

And in a rotating system kinetic energy is

$$KE = \frac{1}{2}I\omega^2 \tag{6-8b}$$

6. Parallel Axis Theorem (Transfer Theorem)

The moment of inertia of a body with respect to any axis (ZZ) can be expressed as the sum of its moment of inertia about an axis (GG) parallel to ZZ through its CG, and the square of the perpendicular distance between those parallel axes.

$$I_{ZZ} = I_{GG} + md^2 \tag{6-9}$$

Where ZZ and GG are parallel axes, GG goes through the CG of the body or assembly, m is the mass of the body or assembly, and d is the perpendicular distance between the parallel axes.

7. Radius of Gyration

The radius of gyration of a body is defined as the radius at which the entire mass of the body could be concentrated such that the resulting model will have the same moment inertia as the original body. The mass of this model must be the same as that of the original body.

8. Equivalent Systems

More complex systems will have multiple masses, springs, and sources of damping connected together. These models can be analyzed by writing dynamic equations for each subsystem and then solving the set of differential equations simultaneously. This allows a multi-degree-of-freedom analysis, with one-DOF for each subsystem included in the analysis.

9. Combining Dampers

(1) Dampers in series. For dampers arranged in series, the force through each damper is the same, and their individual displacements and velocities are different. The reciprocal of the effective damping of the dampers in series is the sum of the reciprocals of their individual damping coefficients.

(2) Dampers in parallel. For dampers arranged in parallel, the force passing through each damper is different, and their displacements and velocities are all the same. The effective damping of the three is the sum of their individual damping coefficients.

10. Combining Springs

Springs are the mechanical analog of electrical inductors.

(1) Springs in series. The force passing through each spring is the same, and their individual displacements are different. A force F applied to the system will create a total deflect which is the sum of the individual deflections. We find that the reciprocal of the effective k of springs in series is the sum of the reciprocals of their individual spring constants.

(2) Springs in parallel. The force passing through each spring is different, and their displacements are all the same. The total force is the sum of the individual forces. We find that the effective k of springs in parallel is the sum of the individual spring constants.

11. Combining Masses

Masses are the mechanical analog of electrical capacitors. The inertial forces associated with all moving masses are referenced to the ground plane of the system because the acceleration in $\boldsymbol{F} = m\boldsymbol{a}$ is absolute. Thus all masses are connected in parallel and combined in the same way as do capacitors in parallel with one terminal connected to a common ground.

12. Solution Methods

Dynamic force analysis can be done by any of several methods. Two will be discussed here, superposition and linear simultaneous equation solution. Both methods require that the system be linear.

Many dynamic force problems typically have a large number of unknowns and thus have multiple equations to solve. The method of superposition attacks the problem by solving for parts of the solution and then adding (superposing) the partial results together to get the complete result. For example, if there are two loads applied to the system, we solve independently for the effects of each load, and then add the results.

Another method writes all the relevant equations for the entire system as a set of linear simultaneous equations. These equations can then be solved simultaneously to obtain the results. This can be thought of as analogous to a "parallel processing" approach. A convenient approach to the solution of sets of simultaneous equations is to put them in a standard matrix form and use a numerical matrix solver to obtain the answers.

13. The Principle of D'Alembert

Newton's second laws are all that are needed to solve any dynamic force system by the Newtonian method. Jean le Rond D'Alembert, a French mathematician, algebraically rearranged Newton's equations to create a "quasi-static" situation from a dynamic one. All D'Alembert did was to move the terms from the right side to the left, changing their algebraic signs in the process as required. The motivation for this algebraic manipulation was to make the system look like a statics problem in which, for equilibrium, forces and torques must sum to zero.

14. Energy Methods—Virtual Work

The Newtonian methods of dynamic force analysis described above have the advantage of providing complete information about all interior forces at pin joints as well as about the external forces and torques on the system. One consequence of this fact is the relative complexity of their application which requires the simultaneous solution of large systems of equations. Other methods are available for the solution of these problems which are easier to implement but give less information. Energy methods of solution are of this type.

Work is defined as the dot product of force and displacement. It can be positive, negative, or zero and is a scalar quantity. Since the forces at the pin joints between the links have no relative displacement associated with them, they do no work on the system, and thus will not appear in the work equation. The work done by the system plus losses is equal to the energy delivered to the system.

Pin-jointed linkages with low-friction bearings at the pivots can have high efficiencies, above 95%. Thus it is not unreasonable, for a first approximation in designing such a mechanism, to assume the losses to be zero. Power is the time rate of change of energy.

Since we are assuming the machine member bodies to be rigid, only a change of position of the CGs (centers of gravity) of the members will alter the stored potential energy in the system. The gravitational forces of the members in moderate- to high-speed machinery often tend to be dwarfed by

the dynamic forces from the accelerating masses. For these reasons we will ignore the weights and the gravitational potential energy and consider only the kinetic energy in the system for this analysis. The time rate of change of the kinetic energy stored within the system for linear and angular motion, respectively, is then

$$\frac{\mathrm{d}\left(\frac{1}{2}mv^2\right)}{\mathrm{d}t}=ma\cdot v \tag{6-10a}$$

and

$$\frac{\mathrm{d}\left(\frac{1}{2}I\omega^2\right)}{\mathrm{d}t}=I\alpha\cdot\omega \tag{6-10b}$$

These are, of course, expressions for power in the system, equivalent to

$$P=F\cdot v \tag{6-10c}$$

and

$$P=T\cdot\omega \tag{6-10d}$$

The rate of change of energy in the system at any instant must balance between that which is externally supplied and that which is stored within the system (neglecting losses). Equation 6-10a and 6-10b represent change in the energy stored in the system, and equation 6-10c and 6-10d represent change in energy passing into or out of the system. In the absence of losses, these two must be equal in order to conserve energy. We can express this relationship as a summation of all the delta energies (or power) due to each moving element (or link) in the system.

$$\sum_{k=2}^{n}F_k\cdot v_k+\sum_{k=2}^{n}T_k\cdot\omega_k=\sum_{k=2}^{n}m_ka_k\cdot v_k+\sum_{k=2}^{n}I_k\alpha_k\cdot\omega_k \tag{6-11a}$$

The subscript k represents each of the n links or moving elements in the system, starting with link 2 because link 1 is the stationary ground link. Note that all the angular and linear velocities and accelerations in this equation must have been calculated, for all positions of the mechanism of interest, from a prior kinematic analysis. Likewise, the masses and mass moments of inertia of all moving links must be known.

If we use the principle of D'Alembert to rearrange this equation, we can more easily "name" the terms for discussion purposes.

$$\sum_{k=2}^{n}F_k\cdot v_k+\sum_{k=2}^{n}T_k\cdot\omega_k-\sum_{k=2}^{n}m_ka_k\cdot v_k-\sum_{k=2}^{n}I_k\alpha_k\cdot\omega_k=0 \tag{6-11b}$$

The first two terms in equation 6-11b represent, respectively, the change in energy due to all external forces and all external torques applied to the system. These would include any forces or torques from other mechanisms which impinge upon any of these links and also includes the driving torque. The second two terms represent, respectively, the change in energy due to all inertia forces and all inertia torques present in the system. These last two terms define the change in stored kinetic energy in the system at each time step. The only unknown in this equation when properly set up is the driving torque (or driving force) to be supplied by the mechanism's motor or actuator. This driving torque (or force) is then the only variable which can be solved for with this approach. The inter-

nal joint forces are not present in the equation as they do no net work on the system.

(From *An Introduction to the Synthesis and Analysis of Mechanisms and Machines* by R. L. Norton)

难句释义

① 全句译为：它远没有达到一个结构化问题描述的要求。

② 全句译为：制作样机通常比较昂贵，但是它是验证设计是否可行的最经济的方法，无须制作与实际完全一样的设备。

③ resistant bodies 等同于 rigid bodies，即“有承载力的物体”。全句译为：机器是多个有承载能力的物体的组合体，它能够强迫自然界的机械力做功，同时伴随着一定的运动。

④ 该句可结合图 6-2 所示的 Geneva 机构理解。全句译为：曲柄还装有一个圆弧段部件，当曲柄销从 Geneva 轮的沟槽中滑动出来时，这个圆弧段就会与 Geneva 轮外缘加工出的圆弧段啮合。

⑤ 该句给出了凸轮从动机构分类的诸多专业词汇。全句可译为：凸轮-从动件系统的分类依据有很多：根据从动件的运动类型分类，可分为平动或转动（振动）；根据凸轮的类型分类，可分为径向的、圆柱的或者三维的；根据接头封闭类型分类，可分为力封闭或形封闭；根据从动件的类型分类，可分为曲面的或平面的，转动的或滑动的；根据运动约束分类，可分为临界极限位置或临界轨迹运动；根据运动顺序分类，可分为升-降、降-停驻或升-停驻-降-停驻。

⑥ their 指代 flat-faced followers，而 they 指代 automobile engine makers。全句译为：平面从动件的数量足以满足汽车发动机制造商提出的任何定制设计需求。

⑦ as 意为“因为”；hop up 原意为“跳起来”，在这里可译为“最需要的”。全句译为：柴油机长期使用滚子从动件（挺杆），因为赛车手们最需要的是高性能发动机。

Unit 7

Design of Machine Elements

7.1 Failure of Elements

Perhaps the most frequently undertaken task in engineering design is the mathematical prediction of failure. A common misconception is that failure of machine parts is due only to breakage—that is, when a part fractures into two or more pieces. In reality, however, there are a number of modes of failure that are based on other failure mechanisms. For this reason, we should seek to identify failure inducing agents and modes of failure. With a knowledge of these, we should then seek a definition of failure that will be applicable to all possible modes of failure.

1. Agents of Failure

The causes of failure in machine parts can be due to the agents of force, temperature, chemical environment, nuclear environment, or metallurgical environment. Each of these cause agents can be a source of failure when they are applied at low, medium, or high levels of value. Each of the cause agents can also be applied steadily over long periods of time, or for very short periods of time (Transient), or even in a cyclic way. If we consider enumerating all combinations of these parameters for failure inducing agents, we see that there are $5 \times 3 \times 3 = 45$ different unique ones that exist. Out of these, some may occur frequently in practice while others may occur hardly at all. For those that occur frequently, names are often given to identify them. For example: Force + High + Transient is often referred to as "impact". Temperature + High + Steady is often a contributing agent to a phenomenon known as "creep".

2. Modes of Failure

The failure-inducing agents act on machine parts to manifest failure in a variety of different ways. Failure modes of machine parts can be categorized by type as elastic, plastic, fracture, or material change. The failure mode can occur suddenly or it may take place over a long period of time. The mode can further be modified according to whether the failure happens at a highly local point on the part, over a surface of the part, or throughout a volume of the part.

3. Definition of Failure

The agents of failure and the modes of failure can combine to give a large number of failure possibilities. What we seek, however, is a definition of failure that encompasses all of these modes and agents for machine parts. The one that we will employ is "Failure will be defined as any change in a

machine part that makes it unable to perform its intended function." Using this definition, we can proceed to develop theories that will enable us to predict when a design is good or when a design will fail.

4. Phenomenological Failure Theories

The best way to predict the strength of a type of engineering material is through an experimental test of a representative sample of that material when subjected to loads similar to those expected in the design. Such a theory is often referred to as a "phenomenological" theory. Phenomenological failure theories will circumvent the unknowns associated with "atomistic" theories.

As an example, suppose that a designer wishes to develop a failure theory for the yielding failure of a machine part. The simple test to be used will be to have a sample piece of the material from which the part is made, stretched in a tensile testing machine in a uniaxial mode until the part yields. The modulus to be used will be the load per unit area (or stress) for the minimum cross section of the specimen. The stress at the point where yielding begins will be called the yield point stress. The hypothesis we will use for our failure theory will be that yielding will happen in a complex part if any of its principal normal stresses exceed this yield point value found in the simple test. This failure theory is known as the maximum normal stress theory of failure.

Stress (the load per unit area) is a common modulus for use in failure theories. It should be kept in mind, however, that stress is not the only modulus that can be used in failure theories. Some modes of failure require the use of other parameters. For example, a failure theory for wear might make use of a modulus that measures the amount of material removed from the surface of a part. A failure theory for corrosion might use a modulus that measures the depth of oxide coating on a part. A failure theory for elastic deflection might use a modulus that depends on the amount of deflection or on the strain.

7.2 Shafts

Shafts are used in all kinds of machinery and mechanical equipment. Although the elementary theory for a circular shaft with static torsional loads is useful, most shafts are subjected to fluctuating loads of combined bending and torsion with various degrees of stress concentration. For such shafts the problem is fundamentally one of fatigue loading. ① In addition to the shaft itself, the design usually must include the calculation of the necessary keys and couplings. The normal operating speed of a shaft should not be close to a critical speed, or large vibrations are likely to develop.

7.2.1 Torsion and Bending Moment of a Shaft

Figure 7-1 shows a circular shaft of uniform cross section loaded at the ends by the torques T, which twist it about the longitudinal axis. The shaft is assumed to be much longer with respect to the diameter than is indicated by the figure. It can be shown experimentally that cross sections perpendicular to the axis before loading remain plane and perpendicular to the axis after the loads T have been applied. The diameter of the bar is unchanged, and radial lines remain straight and radial after

twisting.

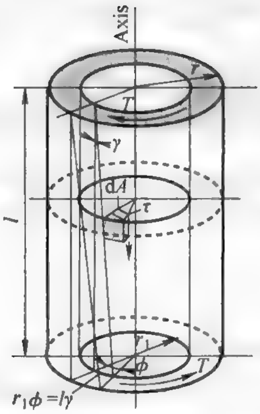


Figure 7-1 Circular shaft twisted by torques at each ends

Many shafts carry combined loads of bending and torque. The bending moment M causes a normal stress in the axial direction of the shaft as shown by σ in Figure 7-2, and the torque T produces the shearing stress τ.

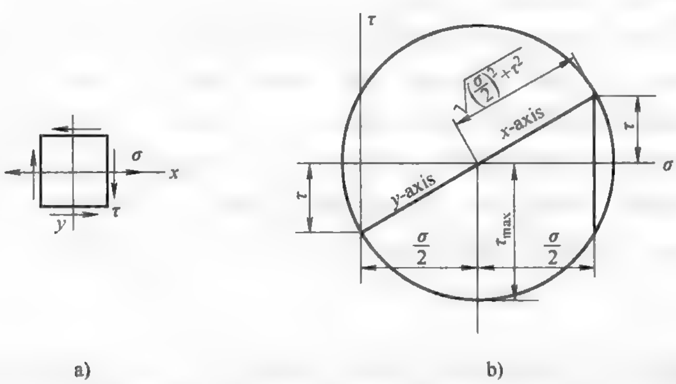


Figure 7-2 Stresses on element of shaft surface

7.2.2 Keys

Shafts and hubs are usually fastened together by means of keys. In addition to a key, set screws are usually employed to keep the hub from shifting axially on the shaft. Generally, two screws are placed in the hub: one screw bears on the key and the other bears on the shaft. It is not a good idea to use a setscrew alone for the transmission of torque. Movement between shaft and hub can be prevented by a taper pin driven tightly into place. The so-called "roll pin" is not solid. It has sufficient flexibility to accommodate itself to small amounts of misalignment and variation in hole diameters, and will not come loose under vibrating loads.

For high-grade construction, and for cases where axial movement between shaft and hub is required, relative rotation is prevented by means of splines machined on the shaft and into the bore. One type of spline uses the involute curve as the outline. The spline on the shaft can be cut by a hobbing process similar to that used for cutting gears.

7.2.3 Couplings

A wide variety of devices is available for connecting the ends of two shafts together. The solid coupling is a typical example. It is inexpensive and will withstand rough usage. Good alignment between the ends of the shafts is necessary, however, to avoid inducing bending stresses in the shafts or loads in the bearings. Many types of flexible couplings are available that provide for some misalignment. Such couplings are often provided with springs or rubber inserts to cushion the shock of suddenly applied loads. Another type of coupling is the universal joint, also known as the Hooke's joint, which has the characteristic that it does not provide a constant angular velocity ratio if the two shafts are not collinear. Proper arrangement of universal joint can cancel out the velocity fluctuations between the driver shaft and the final driven shaft.

7.2.4 Materials Used for Shafting

When service requirements are not too severe, the least expensive shaft material is hot-rolled, plain-carbon steel. For maximum machinability, a normalizing or annealing treatment may be necessary to improve the grain structure and to secure uniformity. Cold-drawn bars, in contrast, have a smooth, bright finish and have diameters held to tolerances of a few thousandths of an inch. Cold drawing improves the physical properties; it raises the values for tensile strength and the yield point. It is available in both plain-carbon and alloy compositions, and is in wide use in the field of general power transmission, since the amount of machining required is minimal.

If greater strength is needed than can be secured by the use of a low-carbon steel in the as-rolled condition, a steel of somewhat higher-carbon content can be used. ② After the machining has been completed, the tensile and yield strengths and hardness can be increased by a quenching and tempering heat treatment. To respond to quenching, the carbon content must be about 0.30% or more. For forged shafts, such as are used in internal combustion engines and railroad cars, the carbon content is usually 0.45% or 0.50%. A widely used steel for such service is plain-carbon steel 45.

When service conditions are more severe, or when certain desirable physical properties are to be obtained, an alloy steel can be used. As a rule, full advantage of the expensive alloying elements can be secured by heat treated. Alloy steels warp and distort less in heat treatment, have less tendency to crack, and have smaller residual stresses than have carbon steels. Meanwhile, alloy steels are tougher, more ductile, and better adapted to shock and impact loads than are plain-carbon steels. For equal hardness, alloy steels are superior in machining qualities. Where considerable machining is required, shop costs can sometimes be reduced by use of a free-cutting steel. This material is high in manganese and has a relatively high machinability rating for a heat-treating alloy steel.

7.3 Springs

When flexibility or deflection in a mechanical system is specifically desired, some form of

spring can be used. Otherwise, the elastic deformation of an engineering body is usually a disadvantage. Springs are employed to exert forces or torques in a mechanism or to absorb the energy of suddenly applied loads. Springs frequently operate with high values for the working stresses, and with loads that are continuously varying.

7.3.1 Materials of Springs

Helical springs are either cold formed or hot formed, depending on the size of the wire. Small sizes are wound cold, but when the bar has a diameter larger than about 3/8 in㊀, the spring is wound from a heated bar.

Numerous materials are used for cold-formed springs. The smaller sizes are stronger because of the greater penetration of the hardening from the drawing. ③ Hard-drawn wire is the cheapest and is commonly used for general-purpose springs, where cost is an important factor. It is used where the stresses are low and where only static loading is present. Springs of this material should not be used at temperatures above 250℉㊁ nor for subzero applications. Music wire is a high-quality and high-carbon steel wire that is widely used in the smaller diameters. The temperature restrictions are the same as for hard-drawn wire.

Oil tempered wire is cold drawn to size and then quenched and tempered. It can be used in many places where the cost of music wire is prohibitive, but is ordinarily not considered suitable where long fatigue life is required. Stainless steel 302 (18% chromium, 8% nickel) has high tensile strength and corrosion resistance. It can be used up to about 550℉ and at subzero temperatures. It has superior creep-resistant properties at the higher temperatures.

The alloy spring steel wires are used where the service conditions are severe, and where shock and impact loads may be present. For severe forming, the wire should be in the annealed condition. When wound from annealed stock, the spring must be heat treated after cooling. These materials are also available in the oil-tempered condition. Valve spring wire, has been developed especially for valve springs and other applications requiring high fatigue properties. Phosphor bronze has good corrosion resistance and electrical conductivity, and is frequently used for contact fingers in switches. Spring brass has similar properties and generally costs less than phosphor bronze. It should not be used above 150℉, but is suitable for subzero applications.

7.3.2 Fatigue of Springs

Since most failures are caused by fatigue, a poor surface is the worst handicap of hot-formed springs. A fatigue crack usually starts at a surface imperfection in a region of stress concentration. The endurance-limit stress for steel bars in the as-rolled condition may be from 30, 000 to 45, 000 psi㊂for both plain-carbon and low-alloy steels. If the surface is badly pitted, the endurance limit

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㊀ in 为英寸，1in = 25.4mm。

㊁ ℉为华氏度，华氏度：摄氏度 × 1.8 + 32。

㊂ psi 的英文全称为 Ponds per square inch，1psi = 6.895kPa。

may be as low as 18, 000 − 20, 000psi. These values for actual springs are thus seen to be much lower than the endurance limit for the same material when polished specimens are tested in the laboratory. A layer of decarburized material on the surface, resulting from the heat treatment, is also a source of weakness, since the endurance limit for the surface may then be less than the working stress for the spring. Decarburization can be avoided if the heat treatment is conducted in a controlled atmosphere. Corrosion, even in a mild form, greatly reduces the fatigue strength. Cadmium plating offers some degree of relief against corrosion.

Shot peening, which leaves the surface in compression, has proved to be very successful in raising the fatigue life of springs. A good surface can also be secured by the use of ground stock and controlled atmospheres, but the costs are relatively high. Such a surface, however, will be spoiled if the spring is subjected to rough usage. If the spring operates under conditions of elevated temperature, there is a danger of creep or permanent deformation unless very low stress values are used. Failure under impact loads at low temperatures can frequently be guarded against by providing a stop to limit the deflection to a safe value.

Many special-type springs for appliances and other products are stamped from flat stock. For high stresses and severe service conditions, the sheared edges of flat springs must be polished to prevent the formation of fatigue cracks.

7.4 Screws

Bolts and screws are used to fasten the various parts of an assembly together. The designer should be familiar with the different kinds of threads in commercial use and with the method of specifying the desired tolerances for the fit between screw and nut. The designer should understand the reasons for the increase of fatigue strength obtained by the application of initial tension in the bolt. Power screws are employed in machines for obtaining motion of translation and also for exerting forces.

7.4.1 Kinds of Threads

In the national standard, the triangle metric thread angle 60° is called the common thread. The same nominal diameter can have a variety of thread pitch, the largest of which is called coarse thread, and the rest is called fine thread. ④ In addition to ordinary fine thread, there are non threaded sealing of the pipe thread (Cylinder wall, $\alpha = 55°$), thread sealing pipe thread (Conical tube wall, $\alpha = 55°$), 60° taper pipe thread. ⑤

For lead screws and power transmissions, the Acme thread is in wide Use. It has an included angle of thread of 29°. In the American National pipe thread, the taper, together with the smaller flat at crest and root, assists in producing a fluid-tight joint. Square threads are used to a limited extent for power transmission.

If an imaginary cylinder, coaxial with the screw, intersects the thread at the height that makes the width of thread equal to the width of space, the diameter of this cylinder is called the pitch

diameter of the screw. The distance measured parallel to the axis from a point on one thread to the corresponding point on the adjacent thread is called the pitch. A screw made by cutting a single helical groove on the cylinder is called a single-thread screw. If the helix angle is somewhat steeper, and a second thread is cut in the space between the grooves of the first, a double-thread screw is formed. For certain applications, triple and quadruple threads are in use. For multiple-thread screws, the lead is the distance of the nut advances in one revolution. ⑥ The pitch is defined as for a single-thread screw. The helix may be cut either right hand or left hand.

7.4.2 Methods of Manufacture

Bolts and screws are nearly always made on automatic forging machines, which give a finished product with practically no scrap loss. Heading is done cold for diameters of 3/4 in. or less, but for larger diameters the end of the bar must be suitably heated. The threads are formed by rolling between dies, which depress part of the material to form the root and which force the remainder up to make the top of the thread. The outside diameter of the thread is thus larger than the stock on which it was rolled. If the threaded portion of the bolt is to have the same diameter as the unthreaded part, the rolling must be done on a reduced diameter. Forging machines form this portion of the smaller cross section at the same time the head is upset. Rolled threads, because of favorable grain structure at the root of the thread, are stronger than cut threads in fatigue and impact.

Bolts can, of course, be made from other kinds of steel as well as nonferrous metals. They can also be turned on automatic screw machines, using free-cutting stock of the same size as the head.

7.5 V-Belts and Chains

Belts, clutches, brakes, and chains are examples of machine elements that employ friction as a useful agent. A belt provides a convenient means for transferring power from one shaft to another. Belts are frequently necessary to reduce the higher rotative speeds of electric motors to the lower values required by mechanical equipment. Clutches are required when shafts must be frequently connected and disconnected. The function of the brake is to turn mechanical energy into heat. The design of frictional devices is subject to uncertainties in the value of the coefficient of friction that must necessarily be used. ⑦ Chains provide a convenient and effective means for transferring power between parallel shafts.

7.5.1 V-Belts

The rayon and rubber V-belt is widely used for power transmission. Such belts are made in two series: the standard V-belt shown and the high-capacity V-belt. The belts can be used with short center distances and are made endless so that difficulty with splicing devices is avoided.

Since the cost of V-belts is relatively low, the power output of a V-belt system may be increased by operating several belts side by side. All belts in the drive should stretch at the same rate in order to keep the load equally divided among them. When one of the belts breaks, the entire group must

usually be replaced. The drive may be inclined at any angle with a tight side at either the top or bottom. Since belts can operate on relatively small pulleys, large reductions of speed in a single drive are possible.

The included angle for the belt groove is usually from 34° to 38°. The wedging action of the belt in the groove gives a large increase in the tractive force developed by the belt.

Pulleys may be made of cast iron, sheet steel, or die-cast metal. Sufficient clearance must be provided at the bottom of the groove to prevent the belt from bottoming as it become narrower from wear. ⑧ Since the cost of cutting the grooves is thereby eliminated, pulleys are on the market that permits an adjustment in the width of the groove. The effective pitch diameter of the pulley is thus varied, and moderate changes in the speed ratio can be secured.

Other types of belts are available for power transmission purposes. Power bands, consisting of V-belts joined along their sides are of assistance in solving the length-matching problem when a number of V-belts must be run side by side. Some types of belts actually have teeth to keep the power transmission process in synchronization.

7.5.2 Roller Chains

A roller chain provides a readily available and efficient method for transmitting power between parallel shafts. Chains present no fire hazard and are unaffected by relatively high temperatures and the presence of oil or grease. Chains are, however, more noisy than belts. A small adjustable idler sprocket should be provided to remove excessive slack from the chain as it wears. It should be located on the outside of the chain on the slack side and near the smaller sprocket.

There are some general guidelines that are helpful to the design of roller chain systems that have evolved from practical experience with the seversatile power transmission systems. Some of these are as follows:

1) A chain length of approximately 100 pitches is close to optimum for the size of most roller chain applications.

2) Sprocket sizes of 17 or more teeth should be used for moderate speeds, and sprocket sizes of 21 or more teeth are best for high-speed drives. Sprockets with fewer than 17 teeth should be used only for very slow-speed drives.

3) Speed ration of a roller chain system should generally not exceed 7 to 1 in a single drive. If higher reductions are needed, two stages of reduction should be used.

4) Roller chain systems that operate near to their maximum capacity are often rather noisy. If quieter designs are desired, it is recommended that the designer uses elements that have a greater power capacity than is actually needed.

5) An increase in capacity can be obtained by the use of multiple-strand roller chains. These are essentially an assembly of single-strand chains placed side by side. The pins extend through the entire width of the chain and maintain the alignment of the different strands. Overhanging shafts should be avoided when using multiple-strand chains unless the shaft it very rigid with a very small deflection.

6) The top chain span of a horizontal roller chain drive should be the right side.

7) The center distance for a roller chain system is optimum in the range of 30 to 50 pitch lengths.

8) Chain wrap around the smaller sprocket in a drive should be at least 120° or 1/3 of the teeth. For speed ratios of over 3 to 1, the center distance must be greater than the difference between the pitch diameters of the two sprockets.

9) Idler sprockets can be used to take up slack in chain drive systems. When they are used, they should be placed outside of the closed span and near to the smaller sprocket on the slack side.

10) The designer should provide a wire mesh or sheet metal guards on roller chain systems to protect both the drive and personnel.

7.6 Lubrication

A lubricant is used to reduce the friction of bearings and sliding surfaces in machines and thus diminish the wear, heat, and possibility of seizure of the parts. Although a layer of oil will eliminate the excessive friction of metal-to-metal contact, the friction within the oil film must be taken into account. The study of lubrication and the design of bearings is, therefore, concerned mainly with phenomena related to the oil film between the moving parts.

The absolute viscosity is the measure of the ability of the lubricant to resist shearing stress. It is a molecular phenomenon, and the work done by force is turned into heat, which raises the temperature of the oil and the surrounding parts. The absolute viscosity of oils is strongly dependent on the temperature of the oil and may decrease by several orders of magnitude as the temperature of the oil is increased.

7.6.1 Dry Friction

Dry friction, or the friction between surfaces without intentional lubrication, is a very complex phenomenon. Despite more than a century of study, a satisfactory explanation of the mechanism of dry friction does not as yet exist. The "classical rules of dry friction" are usually stated as follows:

1) The friction force is directly proportional to the force pressing the bodies together.

2) The friction force is independent of the area of the contacting surfaces.

3) The friction force is largely independent of the velocity of sliding.

4) The friction force depends on the nature of the sliding surfaces.

The coefficient of static friction for bodies at rest, or with motion impending, is somewhat greater than for kinetic friction which prevails after the sliding member is set in motion.

When bodies with very smooth surfaces are brought into intimate contact, adhesive or cohesive forces come into action and hold the bodies tightly together. Thus, when gage blocks or optical flats are wrung together, a relatively large force may be required for tangential motion even though the normal force pressing them together is very small. The classical rules of friction do not apply under such conditions.

A surface of naked metal can be obtained by removal of the oxide and surface film and degreasing in the laboratory. When two metallic surfaces of this kind are brought together in a vacuum or inert atmosphere, the metals weld together at the high spots where contact occurs between them. When one body is drawn along the other, the welds will be made and broken continuously. The resulting motion is somewhat jerky or discontinuous and has been given the name of stick slip. The force required to produce motion under such conditions is relatively very large and may be as much as 20 times the value for corresponding contaminated surfaces. The force also depends upon the velocity of sliding and is thus not in accord with the classical rules of friction.

When two bodies with contaminated surfaces are brought together, actual contact occurs only at the high spots of the two surfaces. The actual area of touching may be only a very small fraction of the nominal area. The contact stress at the isolated points where the bodies touch reaches very high values. Such stresses are required to deform the asperities sufficiently to permit motion to take place. Under such conditions of extreme stress, the surface film may rupture and the welding phenomenon described may take place. Such welding, together with any adhesive forces that may be present, serves to further complicate the situation.

The wide scatter in the published values for the coefficient of friction is undoubtedly due to the lack of precise information on the conditions of the actual surfaces being tested. "In view of the extremely high friction found with really clean metals, it is fortunate, for engineering, that metals are not found with perfectly clean surfaces in practice."

7.6.2 Boundary or Thin-Film Lubrication

Machine parts coated with, a lubricant and rubbing together without benefit of a fluid film are a common occurrence in machinery. Such operation can also occur in a journal bearing for low values of the viscosity or speed or for high values for the load. Such action, known as boundary lubrication, can also occur during starting, stopping, or the reversing of journal bearings. It can also occur during the running-in period of a new machine. The separation of the surfaces is of molecular dimensions.

The rules previously stated for dry friction apply also to boundary lubrication, with the following additions:

1) The friction force depends on the composition of the lubricant and its reaction with the contacting surfaces.

2) The friction force is influenced by the temperature and surface roughness of the bodies.

3) The friction force is independent of the viscosity of the lubricant. The ordinary rules of hydrodynamic lubrication do not apply to boundary lubrication, and design equations for this type of service are not available.

Fatty acids, as found in certain animal and vegetable oils, can be added in small quantities to the lubricant to give a friction-reducing quality distinct from the viscosity of the lubricant. [9] These react with the surfaces to form very tough and durable coatings, and at the same time provide a plane of low shearing strength on which the relative motion between the parts takes place. Massive seizure between the parts is thus prevented.

Boundary lubrication breaks down at elevated temperatures, resulting in a large increase in the coefficient of friction accompanied by wear and surface damage. True boundary lubrication is difficult to achieve even in the laboratory. Usually, there will be sufficient lubricant present to form localized patches of film, which carry part of the load while the remainder of the surfaces are rubbing without complete separation of the peaks of the two surfaces. The result is the so-called mixed lubrication.

7.6.3 Mixed or Semifluid Lubrication

Mixed lubrication, represents a partial breakdown of the full hydrodynamic film as might occur under heavy loads, slow speed, and low viscosity. An insufficient supply of lubricant as given by drip cups or wick oilers may be a contributing factor. Bearing and journal should be made of materials that experience has shown will operate together satisfactorily. Mixed lubrication can also occur when starting a heavily loaded bearing that has been inactive for some time.

Many other means are available for achieving lubrication in mechanical equipment. Some of these are slider bearings, hydrostatic bearings, and gas bearings.

7.7 Bearing

7.7.1 Bearing Materials

Some of the qualities required in a material for a sleeve bearing are load-carrying capacity, thermal conductivity, low coefficient of friction, smoothness of surface, and resistance to wear, fatigue, and corrosion. No one material can possess all the desired characteristics to a sufficient degree, and it is necessary to compromise in most designs.

(1) Tin-and lead-base babbitts. Babbitt bearings are in very wide use and are of two general types: tin base and lead base. They are quickly run in and assume very smooth surfaces. Thickness of the lining is usually about 0.015in.

(2) Bronze bearings. Bronze bearings are suitable for high loads and slow speeds, but the alignment between shaft and bearing must be good.

(3) Copper-lead bearings. These bearings are used where the loads are higher than can be carried by babbitt. The conformability, however, is less and consequently such bearings must be used where the shafts are rigid and the alignment is good.

(4) Cast iron bearings. Cast iron is a bearing material widely used where the service is not too severe. The alignment between journal and bearing, however, must be good. Cast iron runs well with phosphor bronze, and also with cast iron, as evidenced by the cylinder block and pistons of internal combustion engines.

(5) Porous bearings. The "self-lubricating" or "porous" bearing is made by sintering powdered metal and then impregnating with oil. Various compositions of bronze are in wide use. Iron is used to a lesser extent. The felt washer can frequently be omitted. Such bearings are available from stock in both cylindrical and spherical form.

(6) Carbon and plastic bearings. For high-temperature service, or where conventional types of lubrication cannot be used, bearings of pure carbon have been satisfactorily employed. Graphite is a layer-lattice solid, and the low friction of such bearings is due to the low resistance to slip between the lattice planes. Teflon has an extremely low coefficient of friction, and requires no oil lubrication. Bearings can be operated at high loads combined with slow or oscillating speeds. Wear resistance is increased by filling with glass fiber, powdered carbon, bronze, or metallic oxides. Bearings can be used under conditions of corrosion, abrasion, or stickiness. Bearings are frequently formed merely by the use of liners cut from Teflon sheet or strips.

(7) Laminated phenolic bearings. These are plastic bearings formed by impregnating paper or fabric with the phenolic resin, forming into shape, and then curing by heat and pressure. Since this is a thermosetting material, subsequent heating will have no effect. Such bearings show good resistance to corrosion, fatigue, and shock. They have been successfully applied to large sizes and heavy loads, such as in the steel mill industry. Water is sometimes used as the lubricant.

(8) Rubber and wood. Soft rubber, lubricated with water, has been used for many years in pumps and general marine service. Lignum vitae and wood are also used for bearings to a limited extent.

(9) Bonded coatings. Molybdenum disulfide, MoS_2, which resembles graphite in appearance possesses very-low-friction characteristics. Like graphite, it has a laminar structure.

7.7.2 Ball Bearings

Ball bearings are used in almost every kind of machine and device with rotating parts. However, such bearings cannot be used indiscriminately without a careful study of the loads and operating conditions. In addition, the bearing must be provided with adequate mounting lubrication, and sealing.

1. Construction and Types

A ball bearing usually consists of four parts: an inner ring, an outer ring, the balls, and the cage or separator. To increase the contact area and permit larger loads to be carried, the balls run in curvilinear grooves in the rings. The radius of the groove is slightly larger than the radius of the ball, and a very slight amount of radial play must be provided. [10] The bearing is thus permitted to adjust itself to small amounts of angular misalignment in the assembled shaft and mounting. The separator keeps the balls evenly spaced and prevents them from touching each other on the sides, where their relative velocities are the greatest.

Ball bearings are made in a wide variety of types and sizes. Single-row radial bearings are made in four series, "extra light, light, medium, and heavy". The heavy series of bearings is designated by 400. Most manufacturers use a numbering system so devised that if the last two digits are multiplied by 5, the result will be the bore in millimeters. The digit in the third place from the right indicates the series number. Thus, bearing 307 signifies a medium-series bearing of 35mm bore. Additional digits, which may be present in the catalog number of a bearing refer to the manufacturer's details. Some makers list deep groove bearings and bearings with two rows of balls.

The radial bearing is able to carry a considerable amount of axial thrust. However, when the

load is directed entirely along the axis, the thrust type of bearing should be used. The angular contact bearing will take care of both radial and axial loads. The self-aligning ball bearing will take care of large amounts of angular misalignment. An increase in radial capacity may be secured by using rings with deep grooves, or by employing a double-row radial bearing.

2. Service Life

Ball bearings were formerly rated on the basis of the compressive stress in the most heavily loaded ball. [11] Except for static loads, experience has shown that the actual cause of failure is fatigue. Fatigue characteristics are thus used for load rating and are dependent on a large extent on experimental results.

The life of a ball bearing is the life in hours at some known speed, or the number of revolutions, that the bearing will attain before the first evidence of fatigue appears on any of the moving elements. Experience has shown that the life of an individual ball bearing cannot be precisely predicted. Fatigue characteristics are thus used for load ratings. Suppose a number of apparently identical bearings are tested under identical conditions. The life at which 10% of them have failed and 90% are good is called the rating life, or L_{10} life, for this bearing. Since high-grade bearings have consistent quality, the median life, or life at which 50% have failed and 50% are good, is generally not more than five times the rating life. When the rating life is taken at one million revolutions, the load C for this life is called the basic rating load.

When a bearing is installed, there is no way of knowing whether it is one of the 90% that are good or one of the 10% that will not attain the rating life. In other words, one can have but 90% confidence that the bearing will achieve or exceed its rating life, usually designated L_{10}. In some cases, a greater degree of reliability is required. The expected life will, of course, be reduced as the reliability requirement is made higher. Let an adjusting factor α (less than 1), be taken such that life L_n is equal to αL_{10}.

3. Friction and Lubrication

Rolling friction prevails, to a large extent, in ball and roller bearings. Ball bearings, in general, have slightly less frictional resistance than high-grade partial journal bearings operating with flooded lubrication. [12] Ball bearings have definitely less friction than journal bearings operating with scanty oil supply.

In fact, for flooded lubrication, the power lost in churning the oil may be greater than the friction of the bearing alone. A very light or thin oil will give lower friction than one whose viscosity is high.

A light coating of oil or grease is all that is required to maintain an oil film between balls and races. When oil lubrication is used, more or less elaborate seals are needed to retain the lubricant. Lubrication by oil mist has proved successful for very high-speed applications. Grease is essentially a soap impregnated with lubricating oil. For rolling bearing service, the oil has viscosity properties similar to SAE 20 or SAE 30. Grease tends to remain in the bearing and protect the surfaces. Therefore, it does not require such elaborate retainers. At low temperature, the balls cut a channel through the grease, but enough oil usually sweats off to provide lubricant.

The lubricant in a ball bearing severs not only to reduce the friction, but to prevent foreign matter, will injure the surface, from entering the bearing. Every effort must be made to protect the highly polished surfaces from grit, water, acids, or anything that will cause scratches or corrosion. Corrosion fatigue is particularly injurious in causing early fatigue failure of the bearing. Fatigue failures are caused by the bearing surface breaking down; small particles of the metal come out and leave pits or spalls. This breakdown is preceded by minute surface cracks, which are developed by repeated stress applications until they become sufficiently large to form zones of local weakness.

4. Mounting of Ball Bearings

For a rotating shaft, relative rotation between shaft and bearing is usually prevented by mounting the inner ring with a press fit and securing it with a nut threaded on the shaft. Excessive interference of metal must be avoided in press fits, or the stretching of the inner ring may decrease the small but requisite internal looseness of the bearing.

Although the outer ring, when the shaft rotates, is mounted more loosely than the inner ring, rotational creep between the ring and housing should be prevented. When two bearings are mounted on the same shaft, the outer ring of one of them should be permitted to shift axially to take care of any differential expansion between shaft and housing.

Shafts or spindles in machine tools and precision equipment that must rotate without play or clearance in either the radial or axial directions can be mounted on preloaded ball bearings. The preloading, which removes all play from the bearing, can be secured in a number of different ways. Close attention must be paid to dimensions and tolerances to secure just enough projection of the ring to remove the play, but not so much as to induce excessive pressure or binding of the balls.

7.7.3 Roller Bearings

When shock and impact loads are present, or when a large bearing is needed, cylindrical and tapered roller bearings are usually used. A roller bearing, in general, consists of the same four elements as a ball bearing: the two rings, the cage, and the rollers. In the cylindrical roller bearing, the flanges on the rings serve to guide the rollers in the proper direction. When the flanges are omitted from one of the rings, the rings can then be displaced axially with respect to each other, and no thrust component can be carried.

In addition to the radial load, the tapered roller bearing can carry a large axial component whose magnitude depends on the angularity of the rollers. The radial load will also produce a thrust component. The outer ring is separable from the remainder of the bearing. In this type of bearing, it is possible to make adjustment for the radial clearance: two bearings are usually mounted opposed to each other, and the clearance is controlled by adjusting one bearing against the other. Double row tapered roller bearings are also available.

Roller bearings, in general, can be applied only where the angular misalignment caused by shaft deflection is very slight. This deficiency is not present in the spherical roller bearing. It has excellent load capacity and can carry a thrust component in either direction. In the flexible roller bearing, the rollers are wound from strips of spring steel, and afterwards are hardened and ground to

size. If desired, the rollers can bear directly on the shaft without an inner ring, particularly if the shaft surface has been locally hardened. This bearing has been successfully applied under conditions of dirty environment.

Because of the tendency of the unguided rollers to skew, needle bearings are particularly adapted to oscillating loads as in wrist pins, rocker arms, and universal joints. For continuous rotation, needle bearings are usually suitable where the loading is intermittent and variable so that the needles will be frequently unloaded and thus tend to return to their proper locations. When the application involves angular misalignment of the shaft, two short bearings end to end are usually better than one bearing with long rollers. The needle bearing is low priced and requires very little radial space.

7.8 Gears

The designer is frequently confronted with the problem of transferring power from one shaft to another while maintaining a definite ratio between the velocities of rotation of the shafts. Another requirement might be the transmission of a specified angular motion from one shaft to the other. Various types of gearing have been developed for this purpose, which will operate quietly and with very low friction losses.

In the friction cylinders of Figure 7-3, the tangential velocities of the surfaces are equal. These cylinders can be transformed into spur gears by placing teeth on them that run parallel to the axes of the cylinders. The circles in Figure 7-3 are then called the pitch circles; their diameters are called the pitch diameters of the gears. The teeth are arranged to extend both outside and inside the pitch circles. When operating together, the teeth of one gear extend to the working-depth circle of the other. Clearance is required to prevent the end of the tooth of one gear from riding on the bottomland of the mating gear.

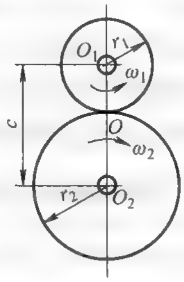

Figure 7-3　Friction cylinders

For positive transmission of motion, the teeth need not be of any particular shape. However, for quiet and vibrationless operation, the velocities of the pitch circles of the two gears must be the same at all times. This statement refers especially to the short interval of time during which two particular teeth are in contact. If the pitch circle of the driver is moving with constant velocity, the shape of the teeth must be such that the velocity of the pitch circle of the driven gear is neither increased nor decreased at any instant while the two teeth are touching. When this condition is satisfied, the gears are said to fulfill the fundamental law of toothed gearing.

7.8.1 Materials for Gears

Gears are made from a wide variety of materials, such as gray and alloy cast iron; cast, wrought, and forged steel; brass; bronze; and impregnated fabric. Cast iron has good wearing properties but is weak in bending, which necessitates the use of relatively large teeth. Unhardened low-

carbon and free-cutting steels can he used for gears but are suitable only for applications requiring moderate strength and impact resistance. Higher strength and surface hardness can be obtained only by some form of heat treatment. The principal production processes for heat treatment are as follows:

(1) Through hardening. With a sufficiently high carbon content, 0.35% to 0.50%, the gear, is quenched and drawn at suitable temperatures to obtain the desired physical properties. The greater strength and hardness of surface and core for heat-treated materials is accompanied by a loss of ductility.

(2) Carburizing or case hardening. In this process, the parts are packed in a compound rich in carbon and held for a long lime at red heat in a furnace. Carbon is absorbed by the surface layers, which become very hard after quenching and tempering. The core is also strengthened, but the gear requires careful handling to prevent distortion.

(3) Nitriding. For extremely hard surfaces and wear resistance, the nitriding process can be used. After heat treatment, the gear is held for an extended period at a temperature of 850 to 1,000°F in the presence of ammonia gas. Complex nitrides form on the surfaces. Nitrided gears can be operated at higher temperatures than carburized gears. Both carburizing and nitriding leave the surface in a state of compressive stress, which is beneficial under the fatigue stresses that occur in gears.

(4) Induction and flame hardening. In this process, the gear is quickly heated by an induction coil followed by quenching in oil. Localized tooth by tooth heating by coil or oxyacetylene flame is also used. Quenching is done by a water spray or an air blast.

Distortion can be eliminated if the teeth are first rough cut in a blank that has been suitably prepared for machining by normalizing or annealing. The gear is then heat-treated to the upper limit for machining, about 300 – 350 Brinell, and the teeth are brought to final size by taking a finish cut.

7.8.2 Lubrication and Mounting of Gears

1. Lubrication

Gears operate under a diversity of conditions, and the methods of lubrication will vary accordingly. For unenclosed or exposed gearing, the lubricant is applied by an oilcan, a drip oiler, or a brush. Frequent applications of small amounts of lubricant are preferable to large volumes at longer intervals. If the gears are exposed to water or acids, a sticky lubricant that will adhere to the metal must be used.

When gears run in an enclosed casing, the larger gears may dip into a bath of oil, which will be carried to the wearing surfaces. Sometimes, enclosed gearing is lubricated by spraying a jet of oil on the working surfaces as they revolve toward each other. When the contact pressure is very high, extreme pressure (EP) lubricants must be used to prevent rupture of the oil film and the resulting metal-to-metal contact of the parts.

2. Mounting

The mounting of gears is very important. Care must be exercised that shafts are parallel or the entire load will be carried at the ends of the teeth instead of across the entire width of the

face. Excessive wear and danger of failure result. The same effect occurs if the teeth are not cut parallel to the axis of rotation or may have other inaccuracies. Elastic deformation of the teeth blanks, shafts, and bearing supports can also be the cause of misalignment. Unbalanced rotating masses in a geared system can also cause unexpected loading, which the teeth are called upon to carry. Noise, vibration, and shortened life can result from many causes, which may be difficult to locate and analyze.

In general, spur gears operate at high efficiencies. Good-quality commercial gears properly mounted and lubricated should not consume in friction more than one or two percent of the power transmitted.

7.8.3 The Failures of Gears

It is very important that a correct analysis be made as to why a pair of gears failed since merely making the set larger may not be a cure for the original cause of the failure. The three most common types of gear tooth failure are tooth breakage, surface pitting, and scoring.

1. Tooth Breakage

Tooth breakage may be caused by an unexpectedly heavy load being imposed on the teeth. A more common type of failure is due to bending fatigue, which results from the large number of repetitions of load imposed on the tooth as the gear rotates. A small value for the radius of the fillet may accentuate the bending fatigue effects.

2. Pitting

Pitting is a surface fatigue phenomenon caused by stresses exceeding the endurance limit the surface material. After a sufficient number of repetitions of the loading cycle, bits metal on the surface will fatigue and drop out. Lubrication difficulties may contribute to pitting failures.

3. Scoring

Scoring can occur under heavy loads and inadequate lubrication. The oil film breaks down and metal-to-metal contact occurs. High temperatures result the high spots of the two surfaces weld together. The welds are immediately broken, but the surfaces of the teeth undergo rapid wear.

It is generally not possible to design a set of gears that will have infinite life with respect to surface-contact stresses since most materials do not exhibit an endurance limit for surface-contact stresses. Thus, gears will eventually fail and most commonly by pitting unless the lubrication is adequate.

7.8.4 Other Gears

Helical, bevel, and worm gears are advanced forms of gearing capable of meeting special requirements of geometry or strength that cannot be obtained from spur gears.

Helical gears have teeth that lie in helical paths on the cylinders instead of teeth that are parallel to the shaft axis. Gears with helical teeth possess certain inherent advantages. More teeth are in contact simultaneously, and the load is transferred gradually and uniformly as successive teeth come into engagement. ⑬ Helical gears thus operate more smoothly and carry larger loads at higher speeds than spur gears. A frequently used application for helical gears is to transmit power between parallel shafts. When such gear sets are used, they mesh with a combination of rolling and sliding, with con-

tact starting at one end of the helical tooth and the contact "wiping" across the face width as the contact progresses.

Helical gears can also be used for transmitting power between nonparallel shafts. When used in this way, the teeth have only point contact, which does not shift axially along the teeth during operation. This severely limits their power-carrying capacity. For this reason, helical gears with nonparallel shafts are usually used only for applications requiring the transmission of relatively small loads.

Bevel gears, with straight or spiral teeth cut on cones, can be used to connect intersecting shafts. A worm gear, consisting of a screw meshing with a gear, can be used to obtain a large speed reduction.

(From *Design of Machine Elements*
by M. F. Spotts, T. E. Shoup and L. E. Hornberger)

难句释义

① 全句译为：这类轴的受力问题从根本上讲属于疲劳载荷作用问题。

② as-rolled 意为"轧制状态"。全句译为：如果使用轧制状态的低碳钢无法达到强度要求，可以使用含碳量更高的钢材。

③ 全句译为：弹簧的尺寸越小强度越大，因为通过冷拔可以获得更大的硬化渗透。

④ fine 在这里不是"好"的意思，而是"细"的意思。全句译为：同样的公称直径下，螺纹可以有很多种螺距，螺距最大的螺纹称为粗牙螺纹，而其余的称为细牙螺纹。

⑤ non threaded sealing of the pipe thread 意为"非螺纹密封管螺纹"；thread sealing pipe thread 意为"螺纹密封管螺纹"。全句译为：除了普通细螺纹外，还有55°非密封管螺纹、55°密封管螺纹以及60°密封管螺纹。

⑥ multiple-thread screws 意为"多头螺钉"，lead 意为"导程"。全句译为：对于多头螺钉，导程是指螺母旋转一圈沿螺钉旋进的距离。

⑦ is subject to 意为"受……影响"。全句译为：摩擦装置的设计必须考虑摩擦系数，因而会受摩擦系数大小不确定性的影响。

⑧ bottoming 意为"V 带底部与 V 槽底接触"。全句译为：带轮槽底必须留有足够的间隙，从而防止 V 带由于磨损而变窄时，引起 V 带底部与 V 槽底的接触。

⑨ distinct from 意为"不同于"，在本句中可译为"与……无关"。全句译为：在润滑油中可以添加少量动物和植物油中提炼的脂肪酸来减小摩擦，该现象与润滑油的黏度无关。

⑩ radial play 意为"径向游隙"。全句译为：沟槽的半径应该比球的半径略大，并且留有少量的径向游隙。

⑪ rate 意为"定级"。全文译为：以前，球轴承的额定寿命是根据最重负载的球所受的压应力确定的。

⑫ partial journal bearing 意为"半围轴承"。全句译为：一般来说，与高精度等级、溢流润滑操作状态下的半围轴承相比，球轴承的摩擦阻力更小。

⑬ engagement 意为"啮合"，and 在此处可译为"因此"。全句译为：更多的轮齿会同时接触，因此当轮齿依次啮合时，可以逐渐地、均匀地传递载荷。

Unit 8

Engineering Materials and Heat Treatment

8.1 Classification of Materials

There are different ways of classifying materials. According to the structures and properties, materials can be classified into metal (including alloys) and nonmetallic materials.

Metals are divided into two general types—ferrous and nonferrous. Ferrous metals are those which contain iron, while nonferrous metals are those which do not contain iron. However, some nonferrous metals may contain a small amount of iron as an impurity.

Nonmetallic is a broad category. It comprises organic materials of natural origin like wood, leather, and natural rubber. It includes materials such as plastics (polymers) and paper which are manufactured at least in part from natural substances. It also includes inorganic materials like glass, ceramics, and concrete, and other materials for special purposes such as semiconductors and composite materials. Table 8-1 shows the representative examples, applications, and properties for commonly used materials.

Table 8-1 Representative examples, applications, and properties for each category of materials

	Examples of Applications		Properties
Metals and Alloys	Copper	Electrical conductor wire	High electrical conductivity, good formability
	Gray cast iron	Automobile engine blocks	Castable, machinable, vibration damping
	Alloy steels	Wrenches, automobile chassis	Significantly strengthened by heat treatment
Ceramics and Glasses	$SiO_2 - Na_2O \sim C_3O$	Window glass	Optically transparent, thermally insulating
	Al_2O_3, MgO, SiO_2	Refractories (i. e., heat-resistant lining of furnaces) for containing molten metal	Thermally insulating, withstand high temperatures, relatively inert to molten metal
	Barium titanate	Capacitors for microelectronics	High ability to store charge
	Silica	Optical fibers for information technology	Refractive index, low optical losses
Polymers	Polyethylene	Food packaging	Easily formed into thin, flexible, airtight film
	Epoxy	Encapsulation of integrated circuits	Electrically insulating and moisture-resistant
	Phenolics	Adhesives for joining plies in plywood	Strong, moisture resistant

(续)

	Examples of Applications		Properties
Semiconductors	Silicon	Transistors and integrated circuits	Unique electrical behavior
	GaAs	Optoelectronic systems	Converts electrical signals to light, lasers, laser diodes, etc.
Composites	Graphite-epoxy	Aircraft components	High strength-to-weight ratio
	Tungsten carbide-cobalt (WC-Co)	Carbide cutting tools for machining	High hardness, yet good shock resistance
	Titanium-clad steel	Reactor vessels	Low cost and high strength of steel, with the corrosion resistance of titanium

Source: Essentials of Materials Science and Engineering by D. R. Askeland and P. P. Phulé.

8.1.1 Ferrous Metals

Steel and cast iron are the most common ferrous metals in general use. Steel is an alloy containing chiefly iron, carbon, and certain other elements in varying amounts. A wide range of physical properties may be obtained in steel by controlling the amount of carbon and other alloying elements and by subjecting the steel to various heat treatments.

Plain carbon steels usually contain, besides iron and carbon, small amounts of silicon, sulphur, phosphorus, and manganese. Alloy steels are formed by the addition of one or more of the following elements: nickel, chromium, molybdenum, vanadium, tungsten, manganese, silicon, and small amounts of other alloying elements.

Carbon is by far the most important alloying element in steel. It is the amount of carbon present which largely determines the maximum hardness obtainable. The higher the carbon content, the higher the tensile strength and the greater the hardness to which the steel may be heat-treated. Low-carbon steels are usually used for low-strength parts requiring a great deal of forming. Medium-carbon steels are used for forgings and other applications where increased strength and a certain amount of ductility are necessary. High-carbon steels are used for high-strength parts such as springs, tools, and dies.

Alloy steels have special properties determined by the mixture and the amount of other metals added. To the metallurgist who works in metal mining and manufacturing, steels containing very small quantities of elements other than carbon, phosphorus, sulphur, and silicon are known as alloy steels. Each alloy steel has a personality of its own. A car is made of about 100 different kinds of alloy steel. Some of the common alloying elements are described below:

Manganese. Manganese helps to reduce certain undesirable effects of sulphur by combining with the sulphur. It also combines with carbon to increase hardness and toughness. Manganese possesses the property of aiding in increasing the depth of hardness penetration. It also improves the forging qualities by reducing brittleness at rolling and forging temperature.

Silicon. Silicon does not normally occur in steels in excess of 3.00 percent. A small amount of silicon improves ductility. It is used largely to increase impact resistance when combined with other

alloys.

Sulphur. Sulphur is generally regarded as detrimental to the hot working of steel and to the impact properties of steel treated to high tensile strength. However, sulphur is an invaluable aid to machining, and steels are often resulphurized to as high as 0.30 percent to gain advantage of this property.

Phosphorus. Phosphorus has an undesirable effect on steel in that it imparts brittleness. There is some evidence that a small amount of phosphorus, less than 0.05 percent, increases tensile strength.

Nickel. Nickel dissolves easily in molten steel. It is present in the common nickel steels in a proportion of 0.40 percent up to 5.00 percent. The addition of nickel increases strength, yield point, hardness, and ductility. It also increases the depth of hardening. Nickel steels are less susceptible to warping and scaling than most other steels. Nickel increases corrosion resistance and is one of the major constituents of the "stainless" or corrosion-resisting steels.

Chromium. Addition of chromium imparts hardness, strength, wear resistance, heat resistance, and corrosion resistance to steels.

Molybdenum. Molybdenum, even in extremely small amounts, has considerable effect as an alloying element on the physical properties of steels. Molybdenum increases elastic limit, impact strength, wear resistance, and fatigue strength. Molybdenum steels are readily heat-treated, forged and machined.

Vanadium. Vanadium is usually used in amounts of less than 0.25 percent. As an alloying agent, vanadium improves fatigue strength, ultimate strength, yield point, toughness, and resistance to impact and vibration. Chromium-vanadium steels have good ductility and high strength.

Tungsten. Tungsten is used largely with chromium as high-speed tool steel which contains 14.00 to 18.00 percent tungsten and 2.00 to 4.00 percent chromium. This steel possesses the characteristic of being able to retain a sharp cutting-edge even though heated to redness in cutting.

Tool-and-Die Steels. Tool-and-die steels are a large group of steels used when careful heat-treating must be done. These steels are used for parts such as chisels, hammers, screwdrivers, springs, and tools and dies used to cut and form metals. Tool steels with certain alloying elements are designed for specific uses. The most common kinds of tool steels include high-speed tool steels, hot work tool steels, cold work tool steels and special-purpose tool steels.

Rolled Steel. Rolled steel, which includes bar, rod, and structural steels, is produced by rolling the steel into shape. Hot-rolled steels are formed into shape while the metal is red-hot. The metal passes through a series of rollers, each a little closer to the next one. As the steel passes through the last rollers, hot water is sprayed over it, forming a bluish scale. This steel is fairly uniform in quality and is used for many different kinds of parts. Hot-rolled bars of the best quality are used to produce cold-finished steels. Cold-finished steels are used when great accuracy, better surface finish, and certain mechanical properties are needed. There are several ways of producing cold-finished bars. The most common results in what is called cold-worked steel. After the scale from the hot-rolled bars is removed, one of two techniques is employed. ① The bars are cold-drawn, that is, drawn through

dies a few thousandths smaller than the original bar. ② The steel is cold-rolled, that is, rolled cold to the exact size.

Drill Rod. Drill rod is a grade of high-carbon tool steel or high-speed steel. It is finished by grinding and polishing so that the outside is smooth and very accurate in size. You can identify drill rod by its shiny surface, which is much smoother than any of the other steels used in the shop. Drill-rod bars are generally made in 3ft[⊖] lengths and come in round, hexagonal, and square shapes. Drill-rod is more expensive than most other steels.

Cast Iron. Cast iron is used for the heavy parts of many machines. It is the most common material for making castings. Cast iron is low in cost and wears well. It is very brittle, however, and cannot be hammered or formed. It contains 2 to 4 percent carbon. The basic kinds of cast iron are white cast iron, gray iron, and malleable iron. Malleable iron is a particular kind of cast iron, made more malleable by an annealing procedure. Malleable-iron castings are not so brittle or hard. They can stand a great deal of hammering. Many plumbing fixtures are made of malleable iron. Nodular iron is a kind of cast iron that is even better for withstanding shocks, blows, and jerks.

(From *Junior Oxford Encyclopedia* by F. H. Mitchel)

8.1.2 Nonmetallic Materials

1. General Properties of Nonmetallic Materials

Nonmetallic materials have varied properties, and few characteristics are applicable to all of them. Two that are almost universal are low electrical and heat conductivity. With the exception of carbon, nonmetallic materials, when dry, are nonconductors.

Nonmetallic materials are usually less tough and less strong than metals, except that the inorganic materials normally have very high compressive strengths. The inorganic materials also have superior high-temperature properties. Resistance to corrosion is a common property with many nonmetallics. Ease of fabrication is a property shared by polymers, wood, and some other organic materials.

2. Polymers: Plastics and Elastomers

A plastic is an organic polymer available in some resin form or a form derived from basic polymerized resin. These forms include liquids and pastes for embedding, coating, and adhesive bonding. They also encompass molded, laminated, or formed shapes including sheet, film, and larger bulk shapes. While there are numerous minor classifications for polymers, depending upon how one wishes to categorize them, nearly all can be placed in one of two major classifications. These two major plastic-material classes are thermosetting materials (or thermosets) and thermoplastic materials. Elastomers are either thermoplastic or thermosetting, depending on their chemical nature.

As the name implies, thermosetting plastics, orthermosets, are cured, set, hardened into a permanent shape. This curing is an irreversible chemical reaction known as cross-linking, which usually occurs under heat. For some thermosetting materials, however, curing is initiated or completed at room temperature. Even then, however, it is often the heat of the reaction, or the exotherm,

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⊖ ft 为英尺，1ft = 304.8mm。

which actually cures the plastic material. Such is the case, for instance, with room-temperature-curing epoxy, polyester, or urethane compounds.

Thermoplastics differ from thermosets in that they do not cure or set under heat. They merely soften, when heated, to a flowable state in which under pressure they can be forced or transferred from a heated cavity into a cool mold. Upon cooling in a mold, thermoplastics harden and take the shape of the mold. Since thermoplastics do not cure or set, they can be remelted and rehardened by cooling many times. Thermal aging, brought about by repeated exposure to the high temperatures required for melting, causes eventual degradation of the material so limits the number of reheat cycles.

The term "elastomers" includes the complete spectrum of elastic or rubberlike polymers which are sometimes randomly referred to as rubbers, synthetic rubbers, or elastomers. More properly, however, rubber is a natural material, and synthetic rubbers are polymers which have been synthesized to reproduce consistently the best properties of natural rubber. Since such a large number of rubberlike polymers exist, the broad term "elastomer" is most fitting and most commonly used.

3. Carbon and Graphite

Carbon is a very common element and the key constituent of all organic materials. In the uncombined pure state, it exists as diamond or graphite. In a less pure state, it exists as charcoal, coal, or coke (amorphous carbon). Both amorphous carbon and graphite are produced in structural shapes when the particles are bonded together with elemental carbon.

Carbon and graphite exhibit properties similar to those of ceramics with two major exceptions. They are electrically and thermally conductive. The ceramic like properties include greater compressive than tensile strength, a lack of malleability and ductility, and a resistance to high temperatures and corrosive environments. The usable temperature limits for carbon and graphite are on the order of 2, 400℃ and even higher. Strength is actually higher at elevated than at room temperatures. Specific electrical resistance ranges from a low of 0.004 Ω/in (graphite) to 0.00220 Ω/in (carbon).

The production of carbon and graphite components involves two processes: molding or extrusion followed by oven baking, and machining. High pressures and consequently significant die or mold costs are involved in the first method, which therefore is economically advantageous only for large-quantity production. Machining is more suitable for limited or moderate quantities.

Carbon and graphite components have mechanical, metallurgical, chemical, electrical, and nuclear applications. Typical uses include electrodes for the production of metals and chemicals in electric-arc furnaces, lighting electrodes, brushes for electric motors, electrodes in electrolytic cells, crucibles, molds for metal casting, resistance-furnace parts, and rocket components when high-temperature and thermal-shock resistance are important.

Carbon and graphite are available in round, square, and rectangular sections. Round bars commonly stocked range from 3 to 1, 100mm in diameter and from 300 to 2, 800mm in length. ① Rectangular bars range from 13mm by 100mm by 400mm long to 600mm by 750mm by 4, 500mm long. ②

Graphite is favored over carbon for applications requiring extensive machining. Graphite ma-

chines fairly well, and tolerances comparable with those of rough machining of metals can be achieved. Carbon members are recommended if only cutoff or other minimum machining is required.

4. Ceramics and Glasses

Ceramics and glasses are inorganic, nonmetallic materials made by fusing clays and other "earthy" materials which usually contain silicon and oxygen in various compositions with other materials. Ceramics are hard, strong, brittle, and heat- and corrosion-resistant and are electrical insulators. They are used when these properties are important, particularly heat and corrosion resistance and electrical nonconductivity. Glass is used when transparency is important in addition to these other properties.

5. Semiconductors

Silicon, germanium, and gallium arsenide -based semiconductors such as those used in computers and electronics are part of a broader class of materials known as electronic materials. The electrical conductivity of semiconducting materials is between that of ceramic insulators and metallic conductors. Semiconductors have enabled the information age. In some semiconductors, the level of conductivity can be controlled to enable their use in electronic devices such as transistors, diodes, etc. , that are used to build integrated circuits. In many applications, we need large single crystals of semiconductors. These are grown from molten materials. Often, thin films of semiconducting materials are also made using specialized processes.

6. Composite Materials

The main idea in developing composites is to blend the properties of different materials. These are formed from two or more materials, producing properties not found in any single material. Concrete, plywood, and fiberglass are examples of composite materials. Fiberglass is made by dispersing glass fibers in a polymer matrix. The glass fibers make the polymer stiffer, without significantly increasing its density. With composites we can produce lightweight, strong, ductile, high temperature- resistant materials or we can produce hard, yet shock-resistant, cutting tools that would otherwise shatter. Advanced aircraft and aerospace vehicles rely heavily on composites such as carbon-fiber-reinforced polymers. Sports equipment such as bicycles, golf clubs, tennis rackets, and the like also make use of different kinds of composite materials that are light and stiff.

(From *Handbook of Product Design for Manufacturing* by J. G. Bralla &
Essentials of Materials Science and Engineering
by D. R. Askeland and P. P. Phulé)

8.1.3 Functional Materials

We can classify materials based on whether the most important function they perform is mechanical (structural), biological, electrical, magnetic, or optical.

1. Aerospace

Light materials such as wood and an aluminum alloy (that accidentally strengthened the engine even more by picking up copper from the mold used for casting) were used in the Wright brothers' historic flight. Today, NASA's space shuttle makes use of aluminum powder for booster rock-

ets. Aluminum alloys, plastics, silica for space shuttle tiles, and many other materials belong to this category.

2. Biomedical

Our bones and teeth are made, in part, from a naturally formed ceramic known as hydroxyapatite. A number of artificial organs, bone replacement parts, cardiovascular stents, orthodontic braces, and other components are made using different plastics, titanium alloys, and nonmagnetic stainless steels. Ultrasonic imaging systems make use of ceramics known as PZT (lead zirconium titanate). Magnets used for magnetic resonance imaging make use of metallic niobium tin-based superconductors.

3. Electronic Materials

As mentioned before, semiconductors, such as those made from silicon, are used to make integrated circuits for computer chips. Barium titanate ($BaTiO_3$), tantalum oxide (Ta_2O_5), and many other dielectric materials are used to make ceramic capacitors and other devices. Superconductors are used in making powerful magnets. Copper, aluminum, and other metals are used as conductors in power transmission and in microelectronics.

4. Energy Technology and Environmental Technology

The nuclear industry uses materials such as uranium dioxide and plutonium as fuel. Numerous other materials, such as glasses and stainless steels, are used in handling nuclear materials and managing radioactive waste. New technologies related to batteries and fuel cells make use of many ceramic materials such as zirconia (ZrO_2) and polymers. The battery technology has gained significant importance owing to the need for many electronic devices that require longer lasting and portable power. Fuel cells will also be used in electric cars. The oil and petroleum industry widely uses zeolites, alumina, and other materials as catalyst substrates. They use Pt, Pt/Rh and many other metals as catalysts. Many membrane technologies for purification of liquids and gases make use of ceramics and plastics. Solar power is generated using materials such as amorphous silicon (a: Si: H).

5. Magnetic Materials

Computer hard disks and audio and video cassettes make use of many ceramic, metallic, and polymeric materials. For example, particles of a special form of iron oxide, known as gamma iron oxide (γ-Fe_2O_3) are deposited on a polymer substrate to make audio cassettes. High-purity iron particles are used for making videotapes. Computer hard disks are made using alloys based on cobalt-platinum-tantalum-chromium (Co-Pt-Ta-Cr) alloys. Many magnetic ferrites are used to make inductors and components for wireless communications. Steels based on iron and silicon are used to make transformer cores.

6. Photonic or Optical Materials

Silica is used widely for making optical fibers. Almost ten million kilometers of optical fiber have been installed around the world. Optical materials are used for making semiconductor detectors and lasers used in fiber optic communications systems and other applications. Similarly, alumina (Al_2O_3) and yttrium aluminum garnets (YAG) are used for making lasers. Amorphous silicon is used to make solar cells and photovoltaic modules. Polymers are used to make liquid crystal displays

(LCDs).

7. Smart Materials

A smart material can sense and respond to an external stimulus such as a change in temperature, the application of a stress, or a change in humidity or chemical environment. Usually a smart-mater ial-based system consists of sensors and actuators that read changes and initiate an action. An example of a passively smart material is lead zirconium titanate (PZT) and shape-memory alloys. When properly processed, PZT can be subjected to a stress and a voltage is generated. This effect is used to make such devices as spark generators for gas grills and sensors that can detect underwater objects such as fish and submarines. Other examples of smart materials include magneto-rheological or MR fluids. These are magnetic paints that respond to magnetic fields and are being used in suspension systems of automobiles. Other examples of smart materials and systems are photochromic glasses and automatic dimming mirrors.

8. Structural Materials

These materials are designed for carrying some type of stress. Steels, concrete, and composites are used to make buildings and bridges. Steels, glasses, plastics, and composites are also used widely to make automotives. Often in these applications, combinations of strength, stiffness, and toughness are needed under different conditions of temperature and loading.

(From *Essentials of Materials Science and Engineering*
by D. R. Askeland and P. P. Phulé)

8.2 Mechanical Properties of Materials

Mechanical properties are measures of how materials behave under applied loads. Another way of saying this is how strong a metal is when it comes in contact with one or more forces. If you know the strength properties of a metal, you can build a structure that is safe and sound. Hence strength is the ability of a metal to withstand loads (forces) without breaking down.

Strength properties are commonly referred to as tensile strength, bending strength, compressive strength, torsional strength, shear strength, fatigue strength and impact strength.

1) Stress is the internal resistance a material offers to being deformed and is measured in terms of the applied load.

2) Strain is the deformation that results from a stress and is expressed in terms of the amount of deformation per centimeter.

3) Elasticity is the ability of a metal to return to its original shape after being elongated or distorted, when the forces are released. A rubber band is a good example of what is meant by elasticity. If the rubber is stretched, it will return to its original shape after you let it go. However, if the rubber is pulled beyond a certain point, it will break. Metals with elastic properties react in the same way.

4) Elastic limit is the last point at which a material may be stretched and still return to its undeformed condition upon release of the stress.

5) Modulus of elasticity is the ratio of stress to strain within the elastic limit. The less a material deforms under a given stress the higher the modulus of elasticity. By checking the modulus of elasticity the comparative stiffness of different materials can readily be ascertained. Rigidity or stiffness is very important for many machine and structural applications.

6) Tensile strength is that property which resists forces acting to pull the metal apart. It is one of the more important factors in the evaluation of a metal.

7) Compressive strength is the ability of a material to resist being crushed. Compression is the opposite of tension with respect to the direction of the applied load. Most metals have high tensile strength and high compressive strength. However, brittle materials such as cast iron have high compressive strength but only a moderate tensile strength.

8) Bending strength is that quality which resists forces from causing a member to bend or deflect in the direction in which the load is applied. Actually a bending stress is a combination of tensile and compressive stresses.

9) Torsional strength is the ability of a metal to withstand forces that cause a member to twist.

10) Shear strength refers to how well a member can withstand two equal forces acting in opposite directions.

11) Fatigue strength is the property of a material to resist various kinds of rapidly alternating stresses. For example, a piston rod or an axle undergoes complete reversal of stresses from tension to compression. Bending a piece of wire back and forth until it breaks is another example of fatigue strength.

12) Impact strength is the ability of a metal to resist loads that are applied suddenly and often at high velocity. The higher the impact strength of a metal the greater the energy required to break it. Impact strength may be seriously affected by welding since it is one of the most structure sensitive properties.

13) Ductility refers to the ability of metal to stretch, bend, or twist without breaking or cracking. A metal having high ductility, such as copper or soft iron, will fail or break gradually as the load on it is increased. A metal of low ductility, such as cast iron, fails suddenly by cracking when subjected to a heavy load.

14) Hardness is that property in steel which resists indentation or penetration. Hardness is usually expressed in terms of the area of an indentation made by a special ball under a standard load, or the depth of a special indenter under a specific load.

15) Cryogenic properties of metals represent behavior characteristics under stress in environments of very low temperatures. In addition to being sensitive to crystal structure and processing conditions, metals are also sensitive to low and high temperatures. Some alloys which perform satisfactorily at room temperatures may fail completely at low or high temperatures. The changes from ductile to brittle failure occur rather suddenly at low temperatures.

(From *Junior Oxford Encyclopedia* by A. M. Perrin)

8.3 Heat Treatment of Steels

Heat treatment is a term applied to a variety of procedures for changing the characteristics of metal by heating and cooling. By proper heat treatment, it is possible to obtain certain characteristics in metal such as hardness, tensile strength, and ductility. Heat treatment can be a simple process requiring few tools. In industry, it is a highly scientific and complicated procedure requiring much equipment.

Many of the projects or products made in the machine shop have little or no value until they are heat-treated. This article includes only the most elementary information about the heat treatment of steel. Heat treatment can also be done on many of the nonferrous metals as aluminium, copper and brass. The procedures are different, however, and will be not considered here.

The procedures of heat treatment of steel include hardening, tempering, annealing, and case hardening.

8.3.1 Hardening

Hardening is a process of heating and cooling steel to increase itshardness and tensile strength, to reduce its ductility, and to obtain a fine grain structure. The procedure includes heating the metal above its critical point or temperature, followed by rapid cooling. As steel is heated, a physical and chemical change takes place between iron and carbon. The critical point, or critical temperature, is the point at which the steel has the most desirable characteristics. When steel reaches this temperature—somewhere between 1, 400 and 1, 600℉—the change is ideal to make for a hard, strong material if it is cooled quickly. If the metal cools slowly, it changes back to its original state. By plunging the hot metal into water, oil, or brine (quenching), the desirable characteristics are retained. The metal is very hard and strong and less ductile than before.

Heating is done in a furnace fired by gas, oil, or electricity. A device called a pyrometer is attached to the furnace. This accurately registers the exact temperature in the furnace. The temperature of the metal can also be determined by observing its colour. You can make use of the colours when heat-treating simple metal parts and tools. Colours are not very accurate, however. Even the expert heat-treater will be off as much as 20℉ from the true temperature.

The hardening procedure is:

1) Light the furnace, and allow it to come to the right temperature.

2) Place the metal in the furnace, and heat it to the critical temperature. For carbon tool steel, allow about 20 to 30 minutes per inch of thickness for coming up to heat. Allow about 10 to 15 minutes per inch of thickness for soaking at hardening temperature.

3) Select the correct cooling solution. Some steels can be cooled in water, and others must be cooled in oil or brine. Water is the most widely used material for quenching carbon steels because it is inexpensive and effective. Brine is usually made by adding about 9 percent of common salt to the water. Brine helps to produce a more uniform hardness. The brine cools the parts all over more quick-

ly. Oil is used for a somewhat slower speed of quenching. Most oils used for quenching are mineral oils.

4) Remove the hot metal with tongs, and plunge it into the cooling solution. Agitate so that the metal cools quickly and evenly. If it is a thin piece (like a knife or blade), cut the cooling solution with the object so it won't warp. If one side cools faster than the other, there will be some warping.

5) A properly hardened piece of steel will be hard and brittle and have high tensile strength. It will also have internal strain. If left in this state, these internal strains could cause the metal to crack.

8.3.2 Tempering

Tempering is a process of reducing the degree of hardness and strength and increasing the toughness. It removes the brittleness from a hardened piece. It is a process that follows the hardening procedure and makes the metal as hard and tough as possible. Tempering is done by reheating the metal to low or moderate temperature, followed by quenching or by cooling in air. As the metal is heated for tempering, it changes in colour. These colours are called temper colours. You can watch these colours to know when the correct heat is reached. A more accurate method, of course, is to watch the pyrometer. Many parts and projects are completely tempered. Others are tempered in one section, and the rest remains in the hardened state.

The tempering procedure is:

(1) To temper the entire piece, place it in the furnace. Reheat to the correct temperature to produce the hardness and toughness you want. Remove the metal and cool it quickly.

(2) To temper small cutting tools:

1) Harden the entire tool. Clean off the scale with abrasive cloth.

2) Heat a scrap piece of metal red hot.

3) Place the tool on the metal with the point extending beyond the hot piece of metal.

4) Watch the temper colours. When the correct colour reaches the point of the tool quench it.

8.3.3 Annealing and Case Hardening

1. Annealing

Annealing is the process of softening steel to relieve internal strain. This makes the steel easier to machine. The metal is heated above the critical temperature and cooled slowly. The most common method is to place the steel in the furnace and heat it thoroughly. Then turn off the furnace, allowing the metal to cool slowly. Another method is to pack the metal in clay, heat it to the critical temperature, remove it from the furnace, and allow it to cool slowly.

2. Case hardening

Case hardening is a process of hardening the outer surface or case of ferrous metal. By adding a small amount of carbon to the case of the low-carbon steel, it can be heat-treated to make the case hard. At the same time the centre, or core, remains soft and ductile.

There are many methods of case hardening. In industry, molten cyanide is used (this is called

cyaniding). Another industrial method is carburizing. This is a case-hardening procedure in which carbon is added to steel from the surface inward by one of the following methods: pack method, gas method, and liquid-salt method. ③

This process can be done on such items as hammer heads, piston pins, and other items that must stand a good deal of shock and wear. It can never be used on anything that must be sharpened by grinding.

(From *Junior Oxford Encyclopedia* by R. Muther)

难句释义

① stock 意为“库存的”。注意尺寸的表示方法，即 in diameter 表示“直径上”，in length 表示“长度上”。全句译为：通常库存的圆形棒料直径为 3 ~ 1100mm，长度为 300 ~ 2800mm。

② 注意尺寸的表示方法，by 表示“乘”。全句可译为：矩形棒料的截面尺寸为 13mm × 100mm ~ 600mm × 750mm，长度为 400mm ~ 4500mm。

③ 主句为“This is a case-hardening procedure”，后面接一个定语从句做状语，“by”后接方式状语。全句译为：这是一个表面硬化工艺，把碳从钢的表面加入向内部渗透达到硬化效果。渗碳方法包括：固体法、气体法和盐浴法。

Unit 9

Manufacturing Technologies—Casting, Forming and Welding

9.1 Casting

9.1.1 Introduction

Casting is one of the earliest metal-shaping methods known to human beings. It generally means pouring molten metal into a refractory mould with a cavity of the shape to be made, and allowing it to solidify. When solidified, the desired metal object is taken out from the refractory mould either by breaking the mould or by taking the mould apart. The solidified object is called casting. This process is also called founding.

1. Advantages and Limitations

The casting process is extensively used in manufacturing because of its many advantages. Molten material flows into any small section in the mould cavity and as such, any intricate shape—internal or external—can be made with the casting process. It is possible to cast practically any material, be it ferrous or non-ferrous. Further, the necessary tools required for casting moulds are very simple and inexpensive. As a result, for trial production or production of a small lot, it is an ideal method. It is possible in casting process, to place the amount of material where it is exactly required. As a result, weight reduction in design can be achieved. Castings are generally cooled uniformly from all sides and therefore they are expected to have no directional properties. There are certain metals and alloys, which can only be processed by casting and not by any other process like forging because of the metallurgical considerations. Castings of any size and weight, even up to 200 tons can be made.

However, the dimensional accuracy and surface finish achieved by normal sand-casting process would not be adequate for final application in many cases. To take these cases into consideration, some special casting processes such as die-casting have been developed. Also, the sand-casting process is labour intensive to some extent and therefore many improvements are aimed at it, such as machine moulding and foundry mechanization. With some materials it is often difficult to remove defects arising out of the moisture present in sand castings. ①

2. Sand Mould Making Procedure

The procedure for making a typical sand mould is described in the following steps.

1) First, a bottom board is placed either on the moulding platform or on the floor, making the surface even.

2) The drag moulding flask is kept upside down on the bottom board along with the drag part of the pattern at the centre of the flask on the board. ② There should be enough clearance between the pattern and the walls of the flask which should be of the order of 50 to 100mm.

3) Dry facing sand is sprinkled over the board and pattern to provide a non-sticky layer. Freshly prepared moulding sand of requisite quality is now poured into the drag and on the pattern to a thickness of 30 to 50mm.

4) The rest of the drag flask is completely filled with the backup sand and uniformly rammed to compact the sand. The ramming of the sand should be done properly so as not to compact it too hard, which makes the escape of gases difficult, nor too loose, so that the mould would not have enough strength.

5) After the ramming is over, the excess sand in the flask is completely scraped using a flat bar to the level of the flask edges.

6) Now, with a vent wire, which is a wire of 1 to 2mm diameter with a pointed end, vent holes are made in the drag to the full depth of the flask as well as to the pattern to facilitate the removal of gases during casting solidification. This completes the preparation of the drag.

7) The finished drag flask is now rolled over to the bottom board exposing the pattern. Using a slick, the edges of sand around the pattern is repaired and the cope half of the pattern is placed over the drag pattern, aligning it with the help of dowel pins. The cope flask on top of the drag is located aligning again with the help of the pins. The dry parting sand is sprinkled all over the drag and on the pattern.

8) A sprue pin for making the sprue passage is located at a small distance of about 50mm from the pattern. Also, a riser pin if required is kept at an appropriate place and freshly prepared moulding sand similar to that of the drag along with the backing sand is sprinkled. The sand is thoroughly rammed, excess sand scraped and vent holes are made all over in the cope as in the drag.

9) The sprue pin and the riser pin are carefully withdrawn from the flask. Later, the pouring basin is cut near the top of the sprue. The cope is separated from the drag and any loose sand on the cope and drag interface of the drag is blown off with the help of bellows.

10) Now, the cope and the drag pattern halves are withdrawn by using the draw spikes and rapping the pattern all around to slightly enlarge the mould cavity so that the mould walls are not spoiled by the withdrawing pattern.

11) The runners and the gates are cut in the mould carefully without spoiling the mould. Any excess or loose sand found in the runners and mould cavity is blown away using the bellows.

12) Finally, the facing sand in the form of a paste is applied all over the mould cavity and the runners, which would give the finished casting a good surface finish.

9.1.2 Materials of Patterns

A pattern is a replica of the object to be made by the casting process, with some modifica-

tions. The main modifications are the addition of pattern allowances, the provision of core prints, and elimination of fine details, which cannot be obtained by casting and hence are to be obtained by further processing.

The usual pattern materials are wood, metal and plastics. The most commonly used pattern material is wood, the main reason being the easy availability and the low weight. Also, it can be easily shaped and is relatively cheap. But the main disadvantage of wood is its absorption of moisture as a result of which distortions and dimensional changes occur. A good construction may be able to reduce the warpage to some extent. Hence, proper seasoning and upkeep of wood is almost a pre-requisite for large-scale use of wood as a pattern material.

The usual varieties of wood commonly used for making patterns are pine, mahogany, teak, walnut and deodar. Besides the wood, the plywood boards of the veneer type as well as the particle boards are also used for making patterns. Because of their availability in various thicknesses, their higher strength and no need for seasoning are the reasons for their usage. However, they can be used only in patterns which are of flat type (pattern plates) and no three-dimensional contours.

The choice of the pattern material depends essentially on the size of the casting, the number of castings to be made from the pattern, and the dimensional accuracy required. For very large castings, wood may be the only practical pattern material. Moulding sand being highly abrasive for large-scale production, wood may not be suitable as a pattern material and one may have to opt for metal patterns.

Because of their durability and smooth surface finish, metal patterns are extensively used for large-scale casting production and for closer dimensional tolerances. ③ Though many materials such as cast iron, brass, etc., can be used as pattern materials, aluminum and white metal are most commonly used. These are light, can be easily worked, and are corrosion resistant. Since white metal has very small shrinkage, the white metal pattern can be made use of for making, additional patterns without worrying about the double shrinkage allowances. ④ Most metal patterns are cast in sand moulds from a master wood pattern provided with the double shrinkage allowance. A comparative study of the advantages and disadvantages of various pattern materials is shown in Table 9-1.

Plastics are also used as pattern materials because of their low weight, easier formability, smooth surfaces and durability. They do not absorb moisture and are therefore, dimensionally stable and can be cleaned easily. The making of a plastic pattern can be done in sand clay moulds or moulds made of Plaster of Paris. The most generally used plastics are cold setting epoxy resins with suitable fillers. With a proper combination it is possible to obtain a no shrink plastic material. In such a case, double shrinkage allowances may not be required.

Table 9-1 Comparative characteristics of metallic pattern materials

Pattern metal	Advantages	Disadvantages
Aluminium alloys	Good machinability High corrosion resistance Low density Good surface finish	Low strength High cost

(续)

Pattern metal	Advantages	Disadvantages
Grey cast iron	Good machinability High strength Low cost	Corrosion prone High density
Steel	Good surface finish High strength	Corrosion prone High density
Brass and bronze	Good surface finish High strength	High cost High density
Lead alloys	High corrosion resistance Good machinability	High cost High density Low strength

Polyurethane foam is also used as pattern material. It is very light and can be easily formed into any shape required. It can be used for light duty work for small number of castings for the conventional casting and for single casting in the case of full mould process where the pattern is burned inside the mould without withdrawing. This plastic has a very low ash content and hence can be burned inside the mould.

The pattern material is to be chosen based on the expected life of the pattern. The following-Table 9-2 gives comparative values of pattern material choices.

Table 9-2 Pattern materials based on expected life

Number of castings produced before pattern equipment repair		
Pattern	**core**	**Pattern Material**
Small castings (under 600mm) 2,000 6,000 100,000	 2,000 6,000 100,000	Hard wood Aluminum, Plastic Cast iron
Medium castings (600 - 1,800mm) 1,000 3,000	 750 3,000	Hard wood Aluminum, Plastic
Large castings (above 1,800 mm) 200 500	 150 500	Soft wood Hard wood metal reinforced

9.1.3 Special Casting Processes

Sand-casting processes described so far are not suitable and economical in many applications. In such situations special casting processes would be more appropriate.

1. Shell Moulding

It is a process in which the sand mixed with a thermosetting resin is allowed to come into contact with a heated metallic pattern plate, so that a thin and strong shell of mould is formed around the pattern. Then the shell is removed from the pattern and the cope and drag are removed together

and kept in a flask with the necessary back-up material and the molten metal is poured into the mould.

Generally, dry and fines and (90 to 140 GFN) that is completely free of the clay is used for preparing the shell moulding sand. The grain size to be chosen depends on the surface finish desired on the casting. Too fine a grain size requires large amount of resin, which makes the mould expensive.

The synthetic res ins used in shell moulding are essentially thermosetting resins, which get hardened irreversibly by heat. The resins most widely used are phenol formaldehyde resins. Combined with sand, they have very high strength and resistance to heat. The phenolic resins used in shell moulding usually are of the two stage type, that is, the resin has excess phenol and acts like a thermoplastic material. During coating with the sand the resin is combined with a catalyst such as hexa methylene tetramine (hexa) in a proportion of about 14% to 16% so as to develop the thermosetting characteristics. The curing temperature for these would be around 150℃ and the time required would be 50 to 60s.

2. Precision Investment Casting

This is the process where the mould is prepared around an expendable pattern. The various steps in the process are shown in Figure 9-1. The first step in this process is the preparation of the pattern for every casting to be made. To do this, molten wax, which is used as the pattern material is injected under pressure of about 2. 5MPa into a metallic die, which has the cavity of the casting to be made. The wax when allowed to solidify would produce the pattern. The pattern is ejected from the die as shown in Step 2. Then the cluster of wax patterns is attached to the gating system by applying heat as shown in Step 3.

To make the mould, the prepared pattern is dipped into a slurry made by suspending fine ceramic materials in a liquid such as ethyl silicate or sodium silicate (Step 4). The excess liquid is allowed to drain off from the pattern. Dry refractory grains such as fused silica or zircon are stuccoed on this liquid ceramic coating (Step 5). Thus, a small shell is formed around the wax pattern. The shell is cured and then the process of dipping and stuccoing is continued with ceramic slurries of gradually increasing grain sizes. Finally, when a shell thickness of 6 to 15mm is reached, the mould is ready for further processing. The shell thickness required depends on the casting shape and mass, type of ceramic and the binder used.

The next step in the process is to remove the pattern from the mould, which is done by heating the mould to melt the pattern (Step 6). The melted wax is completely drained through the sprue by inverting the mould. Any wax remnants in the mould are dissolved with the help of the hot vapor of a solvent, such as trichloro-ethylene.

The moulds are then preheated to a temperature of 100 to 1, 000℃, depending on the size, complexity and the metal of the casting. This is done to reduce any last traces of wax left off and permit proper filling of all mould sections, which are too thin to be filled in a cold mould.

The molten metal is poured into the mould under gravity, under slight pressure, by evacuating the mould first (Step 7). The method chosen depends on the type of casting.

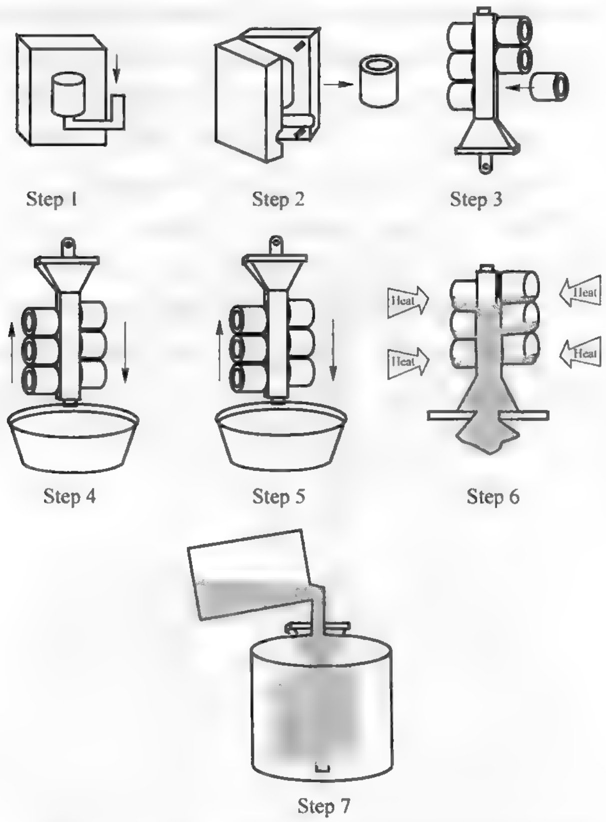


Figure 9-1 Steps in precision investment casting process

Other pattern materials used are plastics and mercury in place of wax. In the process called Mercast, the mercury is kept under −57℃ where the mercury is frozen. The complete mould preparation is to be undertaken at a temperature below −38℃. The main advantage of mercury as a pattern material is that it does not expand when changed from solid to liquid state as wax. However, the main disadvantage is keeping the pattern at such low temperature, which is responsible for its diminishing use.

3. Permanent Mould Casting

In all the processes that have been covered so far, a mould need to be prepared for each of the castings produced. For large-scale production, making a mould for every casting to be produced may be difficult and expensive. Therefore, a permanent mould, called die may be made from which a large number of castings, anywhere between 100 to 250, 000 can be produced, depending on the alloy used and the complexity of the casting. [5] This process is called permanent mould casting or gravity die-casting, since the metal enters the mould under gravity.

The mould material is selected on the consideration of the pouring temperature, size of the casting and frequency of the casting cycle. They determine the total heat to be borne by the die. Fine-grained grey cast iron is the most generally used die material. Alloy cast iron, C20 steel and alloy steels (H11 and H14) are also used for very large volumes and large parts. Graphite moulds may be

used for small volume production from aluminium and magnesium. The die life is less for higher melting temperature alloys such as copper or grey cast iron.

For making any hollow portions, cores are also used in permanent mould casting. The cores can be made out of metal or sand. When sand cores are used, the process is called semi-permanent moulding. The metallic core cannot be complex with undercuts and the like. Also, the metallic core is to be withdrawn immediately after solidification; otherwise, its extraction becomes difficult because of shrinkage. For complicated shapes, collapsible metal cores (multiple piece cores) are sometimes used in permanent moulds. Their use is not extensive because of the fact that it is difficult to securely position the core as a single piece as also due to the dimensional variations that are likely to occur. Hence, with collapsible cores, the designer has to provide coarse tolerance on these dimensions. A typical permanent mould is shown schematically in Figure 9-2, with the various components present which is very similar to the sand mould.

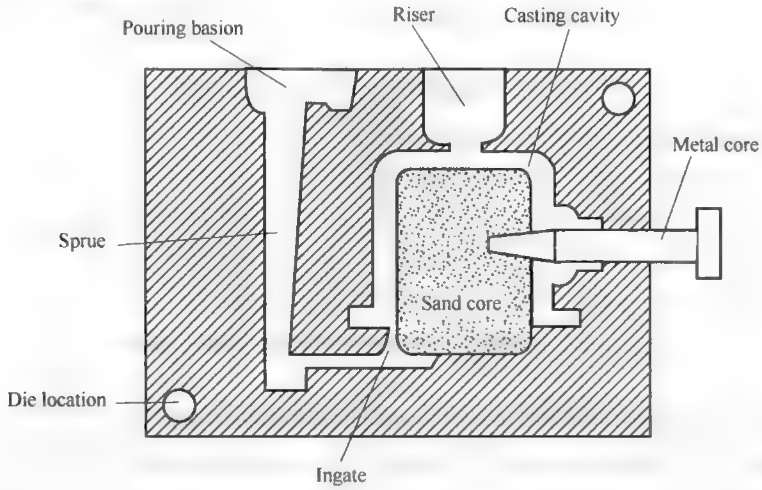


Figure 9-2 Schematic of a permanent mould die with various possible elements

4. Die Casting

Die casting involves the preparation of components by injecting molten metal at high pressure into a metallic die. Die casting is closely related to permanent mould casting, in that both the processes use reusable metallic dies. In die casting, as the metal is forced in under pressure compared to permanent moulding, it is also called pressure die casting. Because of the high pressure involved in die casting, any narrow sections, complex shapes and fine surface details can easily be produced.

In die casting, the die consists of two parts. One part is called the stationary half or cover die which is fixed to the die casting machine. The second part is called the moving half or ejector die that is moved out for the extraction of the casting. The casting cycle starts when the two parts of the die are apart. The lubricant is sprayed on the die cavity manually or by the auto lubrication system so that the casting will not stick to the die. The two die halves are closed and clamped. The required amount of metal is injected into the die. After the casting is solidified under pressure, the die is opened and the casting is ejected. The die casting die needs to have the provision of ejectors to push

the casting after it gets solidified as shown in Figure 9-3. It will also have cooling channels to extract the heat of the molten metal to maintain proper die temperature.

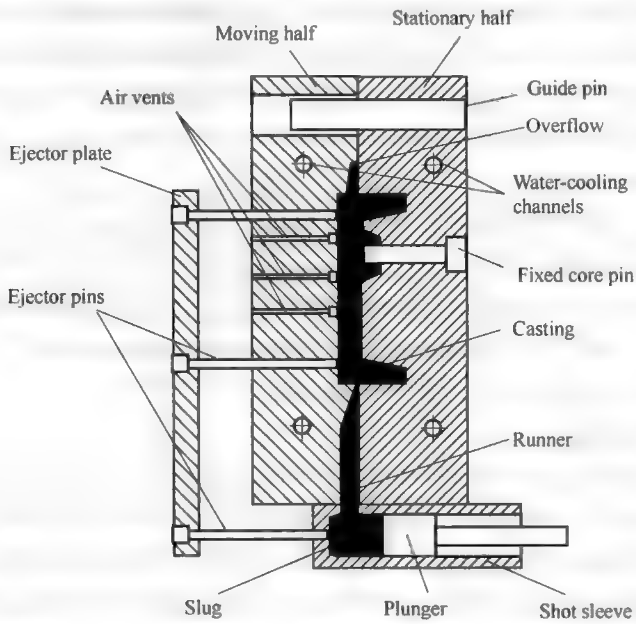


Figure 9-3 Cross section of a die casting die used for cold chamber die casting

The die casting machines are of two types: hot chamber die casting, and cold chamber die casting. The main difference between these two types is that in the hot chamber machine, the holding furnace for the liquid metal is integral with the die casting machine, whereas in the cold chamber machine, the metal is melted in a separate furnace and then poured into the die casting machine with a ladle for each casting cycle which is also called shot.

5. Vacuum Die Casting

The major problem with die casting is the air left in the cavity when the die is closed. Since that air cannot escape, it ends up inside the casting. As a result, when the casting is heat treated, blisters appear on the surface. Also, the molten metal when injected experiences this back pressure in the die cavity. This problem is solved by evacuating the air from the die after the die is closed and before the metal is injected. Thus, the metal enters much faster into the die, thereby decreasing the fill time, and at the same time the parts do not experience any porosity due to the removal of all the air in the cavity. The part is exposed to atmospheric air only after solidification, and as such the oxidation of the material is avoided. It would be possible with the vacuum die casting (VDC) to process parts with very thin walls (1 to 12mm), tight tolerances, fine microstructure due to the rapid solidification rates, and therefore have properties approaching that of wrought product, and with relatively short cycle times.

6. Low-Pressure Die Casting

Though this process is not new, it has been adopted generally for casting aluminum-and magnesium-based alloys. In this process, the permanent mould and the filling system are placed over the

furnace containing the molten alloy. Then, compressed gas is used at a pressure typically ranging from 0.3 to 1.5 bars to force the molten metal to raise slowly through the ceramic riser tube that is connected to the mould. Once the mould cavity is filled, the pressure in the crucible is removed, and the residual molten metal in the tube flows back to the crucible. After the casting is solidified, the side die opens and the top die is raised vertically. The casting will move with the top die owing to the shrinkage and will be ejected onto a transfer tray.

7. Centrifugal Casting

This is a process where the mould is rotated rapidly about its central axis as the metal is poured into it. Because of the centrifugal force, a continuous pressure will be acting on the metal as it solidifies. The slag, oxides and other inclusions being lighter, gets separated from the metal and segregates toward the centre. There are three main types of centrifugal casting processes. They are true centrifugal casting, semi- centrifugal casting, and centrifuging.

8. Continuous Casting

Generally, the starting point of any structural steel product is the ingot which is subsequently rolled through a number of mills before a final product such as a slab or a bloom. However, the wide adoption of continuous casting has changed that scenario by directly casting slabs, billets and blooms without going through the rolling process. This process is fast and is very economical.

In this process, the liquid steel is poured into a double-walled, bottomless water-cooled mould where a solid skin is quickly formed and a semi-finished skin emerges from the open mould bottom. The skin formed in the mould is about 10 to 25mm in thickness and is further solidified by intensive cooling with water sprays as the casting moves downwards.

9. Squeeze Casting

This process was originally developed in Russia and has undergone considerable improvement subsequently. The product quality is greatly improved in this process by solidifying the casting under heavy pressure to prevent the formation of shrinkage defects and retain dissolved gases in solution until freezing is complete. Thus, it is a combination of casting and forging.

9.2 Forming

9.2.1 Hot Working and Cold Working

The metal-working processes are traditionally divided into hot-working and cold-working processes. The division is on the basis of the amount of heating applied to the metal before applying the mechanical force. Those processes, working above the recrystallization temperature, are termed hot-working processes whereas those below are termed cold-working processes.

Under the action of heat and force, when the atoms reach a certain higher energy level, the new crystals start forming which is termed as recrystallization. Recrystallization destroys the old grain structure deformed by mechanical working, and entirely new crystals, which are strain-free, are formed. The grains, in fact, start nucleating at the points of severest deformation. Recrystallization

temperature as defined by the American Society of Metals is "the approximate minimum temperature at which complete recrystallization of a cold-worked metal occurs within a specified time".

The recrystallization temperature generally varies between one-third to half the melting point of most of the metals. Typical values of recrystallization temperatures are given in Table 9-3. The recrystallization temperature also depends on the amount of cold work a material has already received. The higher the cold work, the lower would be the recrystallization temperature.

Table 9-3 Minimum recrystallization temperatures

Material	Recrystallization temperature, ℃	Material	Recrystallization temperature, ℃
Lead	Below room temperature	Iron	450
Tin	Below room temperature	Nickel	600
Cadmium	Room temperature	Titanium	650
Zinc	Room temperature	Beryllium	700
Magnesium	150	Molybdenum	900
Aluminium	150	Tantalum	1,000
Copper	200	Tungsten	1,200

In hot working, the process may be carried above the recrystallization temperature with or without actual heating. For example, for lead and tin, the recrystallization temperature is below the room temperature and hence working of these metals at room temperature is always hot working. Similarly for steels, the recrystallization temperature is of the order of 1,000℃, and therefore working below that temperature is still cold working only.

In hot working, the temperature at which the working is completed is important since any extra heat left after working will aid in the grain growth, thus giving poor mechanical properties. The effect of temperature of completion of hot working is shown schematically in Figure 9-4. A simple heating is shown in A, where the grains start growing after the metal crosses the recrystallization temperature. When it is cooled without any hot working as in B, the final grain size would be larger than when started in A. After heating, when the metal is worked, because of recrystallization, the grain size is reduced. This is made possible because the working of metal gives rise to a large number of nucleation sites for the new crystals to form. If the hot working is completed much above the recrystallization temperature as in C, the grain size starts increasing and finally may end up as a coarse grain size. This increase in size of the grains occurs by a process of coalescence of adjoining grains and is a function of time and temperature. This is not generally desirable. If the hot working is completed just above the recrystallization temperature as in D then the resultant grain size would be fine.

9.2.2 Basic Forming Processes

1. Rolling

Rolling is a very economical process for producing large volumes of material with constant cross-section. It is a process where the metal is compressed between two rotating rolls for reducing its cross-sectional area. This is one of the most widely used of all the metal working processes, because of its higher productivity and low cost. Rolling would be able to produce components having constant cross

section throughout its length. Many shapes such as I, T, L and channel sections are possible, but not very complex shapes. It is also possible to produce special sections such as railway wagon wheels by rolling individual pieces.

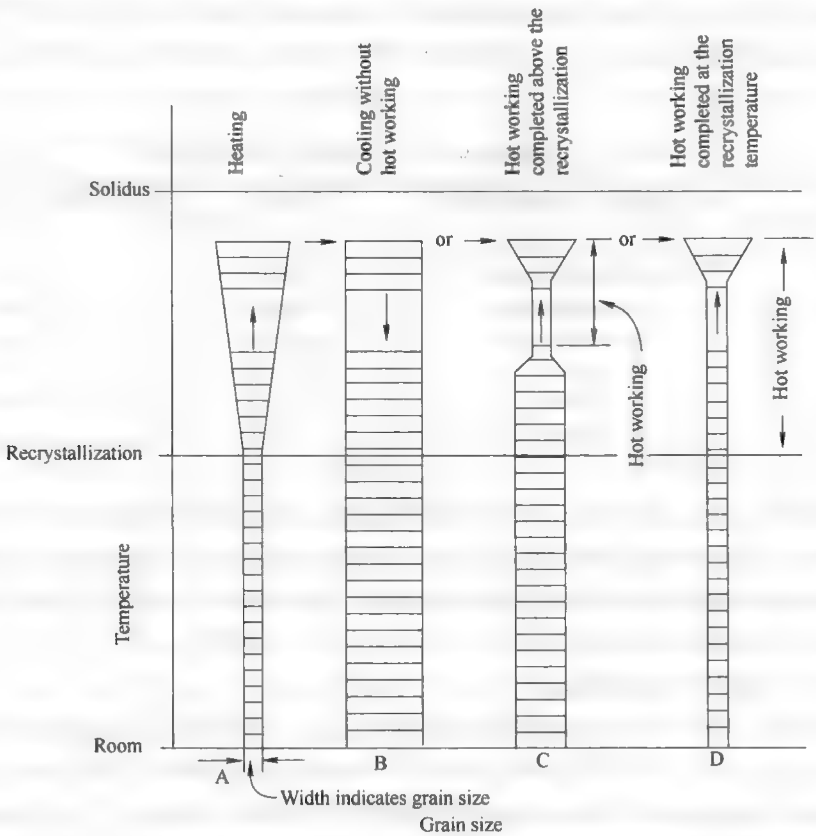


Figure 9-4 Schematic representation of grain size as affected by hot working

2. Forging

Forging is the operation where the metal is heated and then a force is applied to manipulate the metal in such a way that the required final shape is obtained. This is the oldest of the metal-working processes known to mankind since the copper age. Forging is generally a hot-working operation though cold forging is used sometimes.

Two types of operations are used in forging in order to arrive at the final object configuration. They are as follows.

(1) Drawing out. This is the operation in which the metal gets elongated with a reduction in the cross-sectional area. For this purpose, the force is to be applied in a direction, perpendicular to the length axis.

(2) Upsetting. This is applied to increase the cross-sectional area of the stock at the expense of its length. To achieve the upsetting, force is applied in a direction parallel to the length axis.

Because of the manipulative ability of the forging process, it is possible to closely control the grain flow in the specific direction, such that the best mechanical properties can be obtained based

on the specific application.

3. Extrusion

Extrusion is the process of confining the metal in a closed cavity and then allowing it to flow from only one opening so that the metal takes the shape of the opening. The operation is identical to the squeezing of toothpaste out of a toothpaste tube.

A typical extrusion process is presented in Figure 9-5. The equipment consists of a cylinder or container into which the heated metal billet is loaded. On one end of the container, the die plate with the necessary opening is fixed. From the other end, a plunger or ram compresses the metal billet against the container walls and the die plate, thus forcing it to flow through the die opening, and acquiring the shape of the opening. The extruded metal is then carried by the metal-handling system as it comes out of the die. A dummy block which is a steel disc of about 40mm (0.50 to 0.75 of diameter) thickness, with a diameter slightly less than the container, is kept between the hot billet and the ram to protect it from heat and pressure.

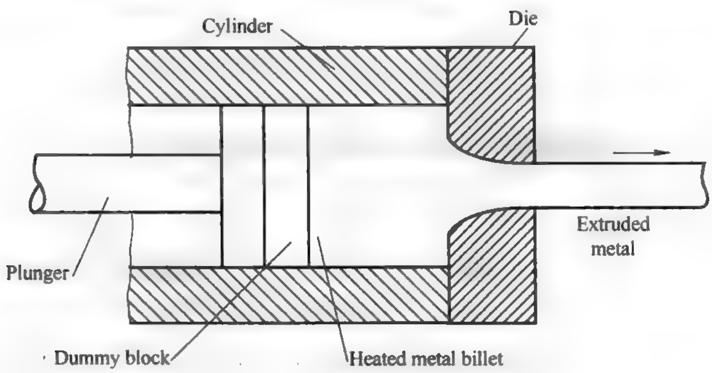


Figure 9-5 Typical extrusion set up

By the extrusion process, it is possible to make components which have a constant cross section over any length as can be had by the rolling process. The complexity of parts that can be obtained by extrusion is more than that of rolling, because the die required is very simple and easier to make. Also, extrusion is a single-pass process unlike rolling. The amount of reduction that is possible in extrusion is large. Generally, brittle materials can also be very easily extruded. It is possible to produce sharp corners and reentrant angles. It is also possible to get shapes with internal cavities in extrusion by the use of spider dies. Large diameters and thin-walled tubular products with excellent concentricity and tolerance characteristics can be produced.

4. Wire Drawing

A wire by definition, is circular with small diameters so that it is flexible. The process of wire drawing is to obtain wires from rods of bigger diameters through a die. Wire drawing is always a cold-working process.

A typical wire-drawing die is shown in Figure 9-6 and the wire-drawing machine in Figure 9-7. The wire-drawing die is of conical shape. The end of the rod or wire, which is to be further reduced, is made into a point shape and inserted through the die opening. This end is then gripped on the oth-

er side with a gripper, which would then pull the wire through the die. The wire thus drawn is then coiled round a power reel as shown in Figure 9-8.

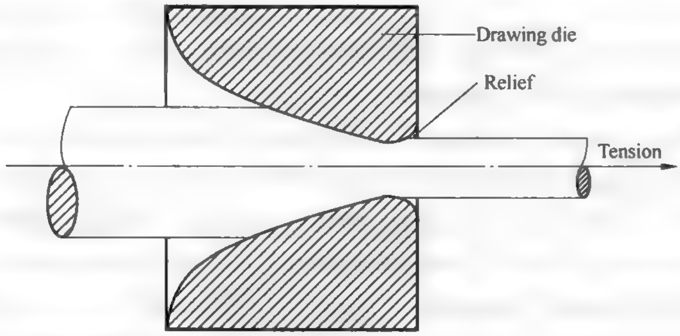


Figure 9-6 Wire-drawing die

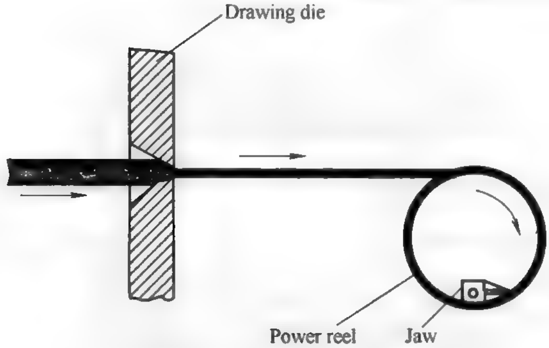


Figure 9-7 Wire-drawing machine set up

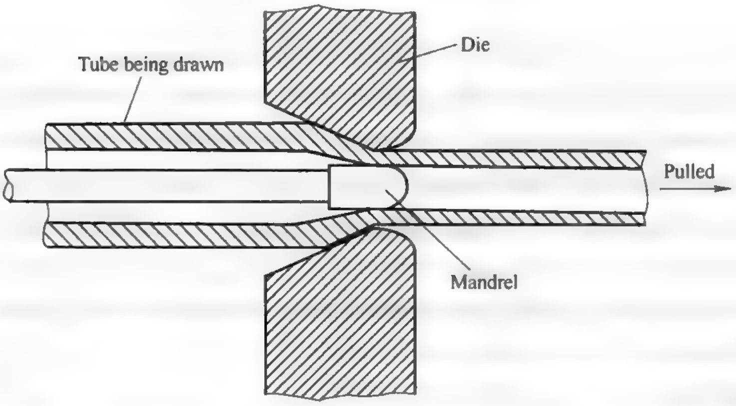


Figure 9-8 Tube drawing with a mandrel

Before the wire is drawn, the stock needs to be prepared for wire drawing. The material should be sufficiently ductile since it is pulled by the tensile forces. Hence, the wire may have to be annealed properly to provide the necessary ductility. Further, the wire is to go through the conical portion and then pulled out through the exit by the gripper. In this process, there is no force applied for

pushing the wire into the die from the entrance side. To make for an easier entrance of wire into the die, the end of the stock is made pointed to facilitate the entry. This pointing is done by means of rotary swaging or by simple hammering.

The other aspect of preparation needed is the cleaning of the wire and lubricating it as it flows through the die. Cleaning is essentially done to remove any scale and rust present on the surface which may severely affect the die. It is normally done by acid pickling. The pressures acting at the interface of the die and the metal being very high, the lubrication of the die is a serious problem. Therefore, to carry the lubricant through the die, special methods such as sulling, coppering, phosphating and liming are used.

5. Rod Drawing and Tube Drawing

Rod drawing is similar to wire drawing except for the fact that the dies are bigger because of the rod size being larger than the wire, but a rod drawn in coiled form is to be straightened first and then cut into proper lengths. ⑥

For larger-sized stock called bars, the heavy equipment which generally keeps the drawn product straight, is used since a bar cannot be coiled. The straight-drawing equipment consists of a table which contains rollers on which the bar stock is fed into the die head after pointing. The point of the bar is then pulled out through the die and put on a carriage. The carriage will be somewhat like an endless chain with grips which grasp the metal protruding from the die and pull along as the chain moves. The bars coming out of the die are generally of short lengths, so that when they are completely drawn, they can be transported to other places from the draw bench.

Tube drawing is also similar to other drawing processes. The main difference is that it requires a mandrel of the requisite diameter to form the internal hole as shown in Figure 9-8. The tubes are also first pointed and then entered through the die where the point is gripped in a similar way as the bar drawing and pulled through in the form desired along a straight line. There may be more than one pass required to get the final size and when the final size is obtained, the tube may be annealed and straightened.

6. Swaging

Swaging is a mechanical deformation technique of reducing or shaping the cross section of rods or tubes by means of repeated impacts or blows. The swaging process consists of dies which are given the requisite external shape. These dies intermittently hammer the stock to produce the deformation. This hammering action, besides producing the necessary shape, ensures good surface qualities, better grain structure and higher tensile strength. It is simple and can be carried out by any unskilled operator.

Since the dies have the necessary taper, the work should be completely clean and dry and without any lubricant. Any lubricant present on the work makes it slip under the tapered portion and feed backwards, causing possible harm to the operator. The types of surfaces generated are external taperings or contours. This is generally used for preparing the pointed tip of the wire before it is put into the wire-drawing die.

Tubes can be swaged with or without the mandrels. In the case of swaging without mandrels, the

surface obtained would not be proper because whenever a blow is applied, the diameter is reduced and length increased. In the process of length increasing, it is possible that the thickness may also increase, in which case the required inside diameter cannot be had and hence, a mandrel is desired.

7. Tube Making

To obtain seamless tubes, extrusion can be used as described earlier. It is also possible to obtain seamless tubes by a variation of rolling called roll piercing. Here, the billet or round stock is rolled between two rolls, both of them rotating in the same direction with their axes at an angle of 4.5 to 6.5 degree as shown in Figure 9-9. These rolls have a central cylindrical portion with the sides tapering slightly. There are two small side rolls, which help in guiding the metal.

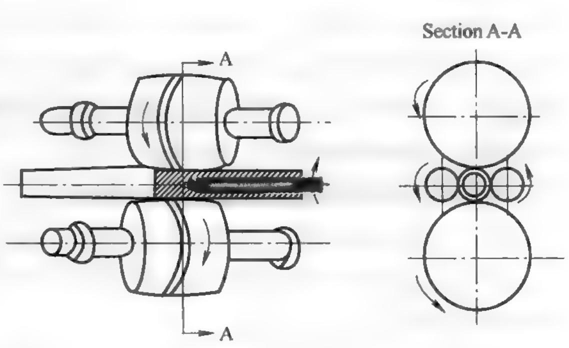


Figure 9-9 Roll-piercing mill arrangement

Because of the angle at which the roll meets the metal, it gets in addition to a rotary motion, an addition axial advance, which brings the metal into the rolls. This cross-rolling action makes the metal friable at the centre which is then easily pierced and given a cylindrical shape by the central-piercing mandrel.

The tube obtained in the roll-piercing mill is further processed in a plug mill, as shown in Figure 9-10, to obtain the desired size. Plug mill is usually a two high reversing stand. It contains a central mandrel to form the tube inner diameter.

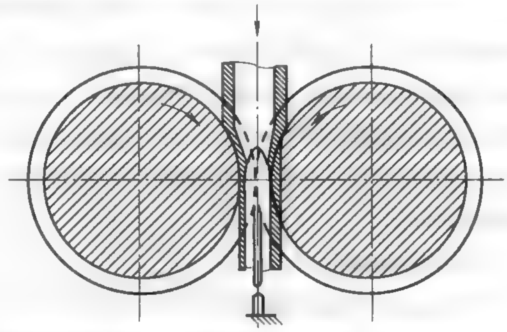


Figure 9-10 Principle of tube rolling in a plug mill

8. Sheet-Metal Operations

Sheet-metaloperations are cold-working operations that manufacture low-cost parts with very high volumes and at a fast rate. Press tool operations, shearing operations, drawing, spinning, bending, stretch forming, embossing and coining are all sheet-metal operation.

9.3 Welding

9.3.1 Fabrication Methods

Joining two or more elements to make a single part is termed a fabrication process. A fairly large number of industrial components are made by fabrication processes. Common examples are aircraft and ship bodies, bridges, building trusses, welded machine frames, sheet-metal parts,

etc. Fabrication is often the most economical method and relies on raw material obtained from one of the primary manufacturing processes such as rolling and extrusion. Hence, it may be called a secondary manufacturing process. The various fabrication processes can be classified as follows:

1) Mechanical joining by means of bolts, screws and rivets.

2) Adhesive bonding by employing synthetic glues such as epoxy resins.

3) Welding, brazing and soldering.

The choice of a particular fabrication method depends on a number of factors pertaining to the joint such as type of assembly—permanent, semi-permanent or temporary, materials being joined—steels, cast irons, aluminum, similar or dissimilar metals, economy achieved, and type of service required—such as assembly subjected to heavy loading, impact loading, high temperatures, etc.

Joining obtained by bolts and screws is temporary in nature and can be disassembled whenever necessary. Rivets are semi-permanent fastening devices, and the joint can be separated only by destroying the rivet without harming the parent elements. These types of mechanical fastening involve making holes in the mating parts, which are to be properly accounted for at the design stage.

Adhesive bonding does not disfigure the joining parts, but would generally have less strength than the mechanical fasteners. But adhesive bonding helps in joining awkwardly shaped parts or thin sheets which may not lend themselves to mechanical fastening. Similarly, metals and nonmetals can be best joined by adhesive bonding as in the case of automobile brake shoe linings. Also, the sandwich structure construction for damping structural vibration, relies on the damping capability of the adhesive.

Adhesives are capable of providing the necessary strength to withstand the applied loads for some applications. The most commonly used adhesives can be classified as thermosetting resins, thermoplastic resins, silicone resins, and elastomers. Out of these, the elastomers, which comprise synthetic and natural rubbers, are elastic in nature and therefore cannot be used for structural applications since they lack the necessary rigidity. However, they can be mixed with thermosetting resins to reduce the brittleness and provide the toughness for shock resistance.

The joint for adhesive application should be properly chosen to provide the necessary cleanliness and the required surface roughness. The type of adhesive chosen should take into account the geometry of the joint, the type of load application and the working conditions such as temperature and humidity. The adhesives are normally applied by either brushing or spraying. The adhesive joint should be cured after assembling, by simple air drying or the more commonly used baking process. The temperature and time control during the curing process is vital for the development of proper strength.

Welding, by contrast to the above fabrication techniques, is a metallurgical fusion process. Here, the interface of the two parts to be joined is brought to a temperature above the melting point and then allowed to solidify so that a permanent joining takes place. Because of the permanent nature of the joint and its strength being equal to or sometimes greater than that of the parent metal, welding is one of the most extensively used fabrication method. Welding is not only used for making structures but also for repair work such as the joining of broken castings. Products obtained by the process of welding are called weldments.

Based on the type of joint and the source of the heat input, the welding processes are classified

as shown in Figure 9-11. The abbreviations shown are those approved by the American Welding Society (AWS). The processes shown are only a fraction of the total spectrum of welding processes. In the subsequent chapters, the details of the more commonly used welding processes are covered.

9.3.2 Basic Welding Methods

1. Gas Welding

As the name implies, gas welding also called oxy-fuel gaswelding (OFW), derives the heat from the combustion of a fuel gas such as acetylene in combination with oxygen. The process is a fusion-welding process wherein the joint is completely melted to obtain the fusion. The heat produced by the combustion of gas is sufficient to melt any metal and as such, is universally applicable.

2. Gas Cutting

For cutting metallic plates, general-purpose shears are used. These are useful for only straight-line cuts and also for cuts up to a thickness of 40mm. For thicker plates and when the cut is to be made along a specified contour, shearing cannot be used. To this end, oxy-fuel gas cutting (OFC) is useful. With oxy-fuel gas cutting, plates up to a thickness as high as 2 meters can be cut with special precautions or methods.

It is possible to rapidly oxidize (burn) iron and steel when it is heated to a temperature between 800 to 1, 000℃. When a high-pressure oxygen jet with a pressure of the order of 300kPa is directed against a heated steel plate, the oxygen jet burns the metal and blows it away causing the cut (kerf). This process invented in 1887 by Thomas Fletcher is extensively used for cutting steel plates of various thicknesses mainly because the equipment required is simple and can be carried anywhere without handling the heavy steel plates.

3. Electric-Arc Welding

In welding, generation of heat by an electric arc is one of the most efficient methods. Approximately, 50% of the energy is liberated in the form of heat. The electric-arc welding process makes use of the heat produced by the electric arc to fusion-weld metallic pieces. This is one of the most widely used welding processes, mainly because of the ease of use and high production rates that can be achieved economically.

An arc is generated between two conductors of electricity, cathode and anode (considering dir3ect current, DC), when they are touched to establish the flow of current and then separated by a small distance. An arc is a sustained electric discharge through the ionized gas column, called plasma, between the two electrodes.

It is generally believed that electrons liberated from the cathode move towards the anode and are accelerated in their movement. When they strike the anode at high velocity, a large amount of heat is generated. Also, when the electrons are moving through the air gap between the electrodes, also called the arc column, they collide with the ions in the ionized gas column between the electrodes. The positively charged ions, move from the anode and impinge on the cathode, thus liberating heat. About 65% to 75% of the total heat is liberated at the anode by the striking electrons. A temperature of the order of 6, 000℃ is generated at the anode.

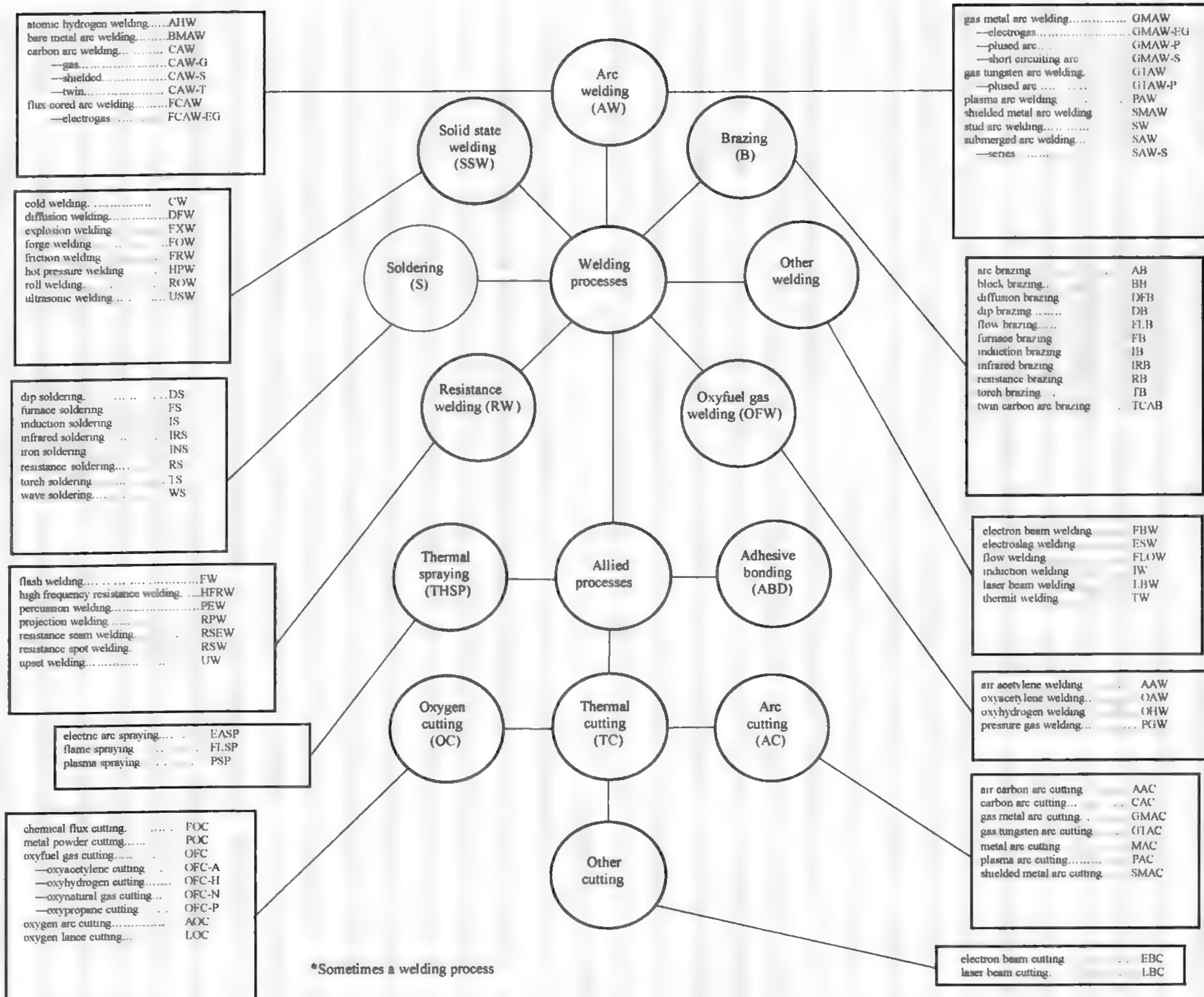


Figure 9-11 Welding classification (courtesy American Welding Society)

In order to produce the arc, the potential difference between the two electrodes (voltage) should be sufficient to allow them to move across the air gap. The larger air gap requires higher potential differences. If the air gap becomes too large for the voltage, the arc may be extinguished. Here, we may make use of an analogy of a person walking on the road. Suddenly, when a deep trench comes in his way, the person would try to jump across it, if it is a short one. However, if it is a broader one, then he may move back a little; come running towards the trench and try to jump over it. If it is too broad, he may abandon the idea of jumping across it. The energy spent in jumping is much more than what is spent while normal walking. In the case of an arc, the extra energy spent crossing the air gap is liberated as heat.

For convenience of explanation, we have chosen a direct current arc for the above description. But even with an arc of the alternating current (AC), it would be similar, with the main difference that the cathode and anode would change continuously and as a result, the temperature across the arc would be more uniform compared to a DC arc.

(1) Manual metal-arc welding. Manual metal-arc welding, also called shielded metal-arc welding (SMAW), is the most extensively used manual welding process, which is done with stick (coated) electrodes. Though in USA, its use is decreasing in comparison to the other arc-welding processes, in India, it still is the most-used arc-welding process. This process is highly versatile and can be used extensively for both simple as well as sophisticated jobs. Further, the equipment is less expensive than those used in most of the other arc-welding processes. Welds by this process can be made in any position.

A job of any thickness can be welded by shielded metal-arc welding, but very small thicknesses below 3mm may give rise to difficulties in welding because of their lack of rigidity. Similarly, very large thicknesses above 20mm may take a long time for filling up the joint groove.

The shielded metal arc welding can be done with either an AC or DC power source. The typical range of the current usage may vary from 50 to 500A with voltages from 20 to 40V.

The main disadvantage of the shielded metal-arc welding process is the slow speed. The typical weld metal-deposition rates may be in the range of 1 to 8kg/h in the flat position. This reduces substantially for the vertical and overhead positions. Further, a lot of electrode material is wasted in the form of unused end, slag and gas. There are more chances of slag inclusions in the bead. Also, special precautions are needed to reduce moisture pick-up so that it does not interfere with the welding.

(2) Carbon arc-welding. Carbon arc-welding is the earliest of the arc-welding processes. In this, the electrode is made of either carbon or graphite. In contrast to graphite electrodes, carbon electrodes are soft and therefore, cannot take up very high current densities. The arc with the carbon electrodes is more controllable. Lower currents also add to the higher electrode life.

Though carbon or graphite electrodes are not expected to melt as the consumable electrodes, they do get heated to a red-hot temperature because of the heat from the arc which causes a slow disintegration of the electrode tip as also its oxidation. This means that this electrode is slowly consumed. For use in carbon arc welding, the electrode should be of uniform structure and, as far as possible, free from impurities. The life of a graphite electrode is higher than that of a carbon elec-

trode.

(3) Inert-gas shielded arc welding. The endeavor of the welder is always to obtain a joint which is as strong as the base metal and at the same time, the joint is as homogeneous as possible. To this end, the complete exclusion of oxygen and other gases, which interfere with the weld pool to the detriment of the weld quality, is very essential. In manual metal-arc welding, the use of stick electrodes does this job to some extent but not fully. In inert-gas shielded arc welding processes, a high-pressure inert gas flowing around the electrode while welding would physically displace all the atmospheric gases around the weld metal to fully protect it.

It all started in 1890 when a patent was granted for welding with an electrode, which was provided with a shielding of flowing carbon dioxide gas. But in 1930, the first use of helium and argon as shielding gases for arc welding with non-consumable electrodes was demonstrated for commercial use. Since then, rapid strides have taken place in gas-shielded arc welding and it is now used extensively.

The shielding gases most commonly used are argon, helium, carbon dioxide and mixtures of them. Argon and helium are completely inert and therefore they provide a complete inert atmosphere around the puddle, when used at sufficient pressure. When these gases are used, they should be of high purity (99.95% purity). Any contamination in these gases would decrease the weld quality. Hydrogen, if present or generated because of the dissociation of moisture, would give rise to weld porosity.

(4) Tungsten inert-gas welding (TIG). Tungsten inert-gas welding or gas tungsten arc welding (GTAW) is an inert-gas shielded arc-welding process using a non-consumable electrode. The electrodes may also contain 1% to 2% thoria (thorium oxide) mixed along with the core tungsten or tungsten with 0.15% to 0.40% zirconia (zirconium oxide). The pure tungsten electrodes are less expensive but will carry less current. The thoriated tungsten electrodes carry high currents and are more desirable because they can strike and maintain a stable arc with relative ease. The zirconia added tungsten electrodes are better than pure tungsten but inferior to thoriated tungsten electrodes.

(5) Gas metal-arc welding (GMAW). Metal inert-gas arc welding (MIG) or more appropriately gas metal-arc welding utilizes a consumable electrode and hence, the term 'metal' appears in the title. There are other gas-shielded arc-welding processes utilizing consumable electrodes, such as flux-cored arc welding (FCAW), all of which can be termed under MIG. Though gas-tungsten arc welding (GTAW or TIG) can be used to weld all types of metals, it is more suitable for thin sheets. When thicker sheets are to be welded, the filler metal requirement makes GTAW difficult to use. In this situation, the GMAW comes handy.

Normally, DC arc-welding machines are used for GMAW with electrode positive (DCEP). The DCEP increases the metal-deposition rate and also provides for a stable arc and smooth electrode metal transfer. With DCEN, the arc becomes highly unstable and also results in a large spatter. Special electrodes having calcium and titanium oxide mixtures as coatings are found to be good for welding steel with DCEN.

(6) Submerged arc-welding (SAW). Submerged arc-welding is used for doing faster welding

jobs. It is possible to use larger welding electrodes (12mm) as well as very high currents (4,000A) so that very high metal-deposition rates of the order of 20kg/h or more can be achieved with this process. Also, very high welding speeds (5m/min) are possible in SAW. Some submerged arc-welding machines are able to weld plates of thicknesses as high as 75mm in butt joints in a single pass. Though submerged arc-welding can be used even for very small thicknesses, of the order of 1mm, it is more economical for larger welds only.

(7) Other arc-welding processes. Besides the various arc-welding processes that have been covered so far, there are other processes available which are used in, a rather, restricted manner. Some of them are atomic hydrogen welding (AHW), plasma arc welding (PAW), stud arc welding (SW), and fire cracker welding.

4. Arc Cutting

In arc cutting, the metal is simply melted by the intense heat of the arc and is then blown away by the force of arc itself or by other gases such as air or shielding gases. It is also possible to burn the gases by sending a jet of oxygen. Depending on the source of heat input, there are various processes such as carbon-arc cutting (CAC), air carbon-arc cutting (AAC), oxygen-arc cutting (AOC), shielded metal-arc cutting (SMAC), gas metal-arc cutting (GMAC), gas tungsten-arc cutting (GTAC) and plasma-arc cutting (PAC).

In all these processes, the equipment used is similar to that used for the corresponding welding process with the exception of the torch which is different. The torch holds the electrode, as also has the provision for the supply of high-pressure gas wherever needed.

Carbon-arc cutting is the simplest process, which uses a carbon electrode to obtain the required arc. The metal that is cut is blown away by the arc force and gravity. This produces very rough edge and therefore finds very little application except in scrap cutting.

In the air carbon-arc cutting, the arc is normally obtained between a copper-coated graphite or carbon electrode and the workpiece with the molten metal being forced out by means of compressed air at a pressure of 550 to 690kPa. It may be possible to use a very low pressure of the order of 280kPa in some manual torches for field application but is not generally recommended. The air consumption is in the range of 85 to 1, 400L/min depending on the thickness of the metal being cut. The copper coating is used to reduce the oxidation of the electrodes and to help cool the electrode.

In oxygen-arc cutting, a hollow tubular electrode is used to obtain the arc. Compressed oxygen is forced through the hollow portion so that the metal is oxidized and blown in a fashion similar to oxy fuel gas cutting (OFC).

The shielded gas-cutting processes (GMAC and GTAC) are used for cutting those materials which have oxidation problems, such as aluminum, stainless steel or nickel alloys. In plasma-arc cutting very high temperatures of the order of 14,000℃ are generated. Therefore, any metal can easily be melted and blown away by this process.

5. Resistance Welding

The welding processes covered so far, are fusion-welding processes where only heat is applied

in the joint. In contrast, resistance welding process is a fusion-welding process where both heat and pressure are applied on the joint but no filler metal or flux is added. The heat necessary for the melting of the joint is obtained by the heating effect of the electrical resistance of the joint and hence, the name resistance welding.

In resistance welding (RW), a low voltage (typically 1V) and very high current (typically 15,000A) is passed through the joint for a very short time (typically 0.25s). This high amperage heats the joint, due to the contact resistance at the joint and melts it. The pressure on the joint is continuously maintained and the metal fuses together under this pressure.

The resistance of the joint, is a complex factor to know because it is composed of the resistance of the electrodes, contact resistance between the electrode and the workpiece, contact resistance between the two workpiece plates, and resistance of the workpiece plates. ⑦ The amount of heat released is directly proportional to the resistance. It is likely to be released at all of the above-mentioned points, but the only place where a large amount of heat is to be generated to have an effective fusion is at the interface between the two workpiece plates. Therefore, the rest of the component resistances should be made as small as possible, since the heat released at those places would not aid in the welding.

(From *Manufacturing Technology* by P. N. Rao)

难句释义

① arising out of 意为“由……引起，产生”。全句译为：在砂型铸造时，一些材料由于湿度引起的缺陷很难消除。

② along with 意为“随着，和……一起”；upside down 意为“颠倒”。全句译为：将下模砂箱反过来放置在底板上，使下箱模型位于砂箱的中央并置于底板上。

③ close 在此处表示“精密的”，常用来修饰 tolerance（公差）。全句译为：由于金属模型耐用性和表面粗糙度值较低，它们被广泛地应用在大规模铸造生产和精密尺寸公差加工的场合。

④ 全句译为：由于断面收缩率很小，使用白色合金制作附加模型时不需要将收缩余量翻倍。

⑤ 此句中 made 和 from 不是一个词组，from 和后面的关系代词 which 放到一起翻译。全句译为：因此，可以制作永久性铸型或刚模来满足大批量铸件的生产。生产的铸件数量可介于 100 到 250,000 个之间，取决于刚模合金种类和铸件的复杂程度。

⑥ 全句译为：棒材拉拔与线材拉拔类似，只是由于尺寸的增大需要采用更大的拔模。但是将棒材拉拔成盘绕形式时，首先需要增大强度，然后切割成合适的尺寸。

⑦ 注意翻译时的多个并列宾语。全句译为：焊接接头的电阻是一个复杂的因素，因为它由电极的电阻、电极和工件的接触电阻、两个工件板的接触电阻和工件板的电阻组成。

Unit 10

Manufacturing Technologies—Metal Cutting and Machine Tools

Of all the manufacturing processes available, metal removal is perhaps the most expensive one. This is because from the raw material, quite a substantial amount of material is removed in the form of chips in order to achieve the required shape. Also, a lot of energy is expended in the process of material removal. So, the choice of material removal as an option for manufacturing should be considered when no other manufacturing process suits the purpose. However, invariably all components undergo a material removal operation at one point or the other.

The various material-removal processing machines that are available are:

- Turning machines (Lathes)
- Boring machines
- Grinding machines
- Gear cutting machines
- Unconventional machining machines
- Drilling machines
- Milling machines
- Shaping and planing machines
- Sawing machines

10.1 Lathes

A lathe is a machine tool which is used for shaping wood or metal; the workpiece turns about a horizontal axis against a fixed tool. Lathe is the oldest machine tool invented, starting with the Egyptian tree lathes. In the Egyptian tree lathe, one end of the rope wound round the workpiece is attached to a flexible branch of a tree, while the other end is pulled by the operator, thus giving rotary motion to the workpiece. This primitive device has evolved over the last two centuries to be one of the most fundamental and versatile machine tools with large variants, to be used practically in all the manufacturing shops.

The principal form of surface produced in a lathe is the cylindrical surface. This is achieved by rotating the workpiece, while the single-point cutting tool removes the material by traversing in a direction parallel to the axis of rotation, as shown in Figure 10-1, and termed as turning. The popularity of lathe is in view of the fact that a large variety of surfaces can be produced.

Considering the versatility, a large number of variants of lathes are used in manufacturing shops.

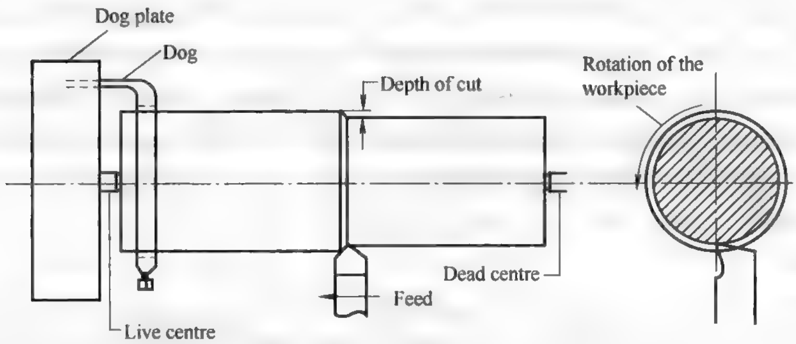


Figure 10-1 Cylindrical turning operation in a lathe

(1) Centre lathe. The centre lathe is the most common lathe, which derives its name from the way a workpiece is clamped by centres in a lathe, though this is not the only way in which the job is mounted. This is sometimes also called engine lathe, in view of the fact that early lathes were driven by steam engines. This is generally used for more general applications, and thus the construction of the machine tool is more rigid.

(2) Tool room lathe. The tool room lathe is generally meant for applications of tool making, where the accuracy desired is much higher than that normally required for general production work. Also, the range of sizes and materials handled is normally large. Thus, the machine would have a higher range of speeds and feeds along with greater rigidity. Also, the range of accessories and attachments is generally larger.

(3) Special purpose lathes. The special purpose lathes are developed from the centre lathe to cater to special forms of application, which cannot be handled by the conventional centre lathe.

(4) Capstan and turret lathes and automatic lathes. Capstan and turret lathes, and automatic lathes are the form of lathes that cater to high rate production, and thus would be used for very special application. These have the special features to help in improving the production rate, and work unattended, if necessary.

10.1.1 Operations Performed in a Centre Lathe

As discussed above, in a lathe it is possible to achieve a large number of surfaces, based on the various settings that are possible.

1. Turning

Turning is by far the most commonly used operation in a lathe. In this, the work held in the spindle is rotated while the tool is fed past the workpiece in a direction parallel to the axis of rotation. The surface thus generated is a cylindrical surface.

2. Facing

Facing is an operation for generating flat surfaces in lathes. The feed, in this case, is given in a direction perpendicular to the axis of revolution. The tool used should thus have all approach angle suitable so that it would not interfere with the workpiece during the tool feeding.

Also, the radius of the workpiece at the contact point of tool varies continuously, as the tool approaches the centre. Thus, the resultant cutting speed continuously varies in facing, starting at the highest value at the circumference, to almost zero near the centre. Since the cutting action and the surface finish generated depend on the actual cutting speed, the finish becomes very poor as the tool approaches the centre. Also, while choosing the rotational speed of the workpiece, due care has to be taken of this fact. ①

3. Knurling

Knurling is a metal working operation done in a lathe. In this, a knurling tool having the requisite serrations is forced on to the workpiece material, thus deforming the top layers. This forms a top surface, which is rough and provides a proper gripping surface.

4. Parting

Parting and grooving are similar operations. In this, a flat-nosed tool would plunge cut the workpiece with a feed in the direction perpendicular to the axis of revolution. This operation is generally carried out for cutting off the part from the parent material. When the tool goes beyond the centre, the part would be severed. Otherwise, a rectangular groove would be obtained. It is also possible, in similar operation, to use a special form of tool to obtain the specific groove shape.

5. Drilling

Drilling is the operation of making cylindrical holes into the solid material. A twist drill is held in the quill of the tailstock, and is fed into the rotating workpiece by feeding the tailstock quill. Since the workpiece is rotating, the axis of the hole is well-maintained, even when the drill enters at an angle initially. The same operation can also be used for other hole making operations, such as centre drilling, counter sinking, and counter boring. This operation is limited to holes through the axis of rotation of the workpiece, and from any of the ends.

6. Boring

Boring is the operation of enlarging a hole already made by a single point boring tool termed as boring bar. The operation is somewhat similar to the external turning operation. However, in view of the internal operation, it is more restricted. The cutting forces experienced are somewhat more than the external operation. Also, the tool used is less rigid compared to turning tool, and as a result, it cannot withstand the large cutting forces. Thus, the process parameters used are somewhat lower than those used for turning. Boring is used for generating an accurate hole with good surface finish.

10.1.2 Special-Purpose Lathes

Though the centre lathe is a general purpose machine tool, it has a number of limitations that preclude it to become a production machine tool. The main limitations of centre lathes are:

1) The setting time for the job in terms of holding the job is large.

2) Only one tool can be used in the normal course. Sometimes, the conventional tool post can be replaced by a square tool post with four tools.

3) The idle times involved in the setting and movement of tools between the cuts is large.

4) Precise movement of the tools to destined places is difficult to achieve without proper care

exercised by the operator.

Due to these difficulties, the centre lathe cannot be used for production work in view of the low production rate. Thus, the centre lathe is modified to improve the production rate. The various modified lathes are turret and capstan lathes, semi-automatics, and automatics. The improvements are achieved basically in the following areas: ①Work holding methods. ②Multiple tool availability. ③Automatic feeding of the tools. ④Automatic stopping of tools at precise locations. ⑤Automatic control of the proper sequence of operations.

10.2 Reciprocating Machine Tools

In the previous section, discussion was centred around the lathes and the various varieties that are generally used for general purpose work as well as for mass manufacture. In the lathes, the component is rotated while the cutting tool is axially moved to generate, generally, cylindrical surfaces. In the present section, the machines which use only reciprocating action, are discussed. The major machine tools that fall in this class are:

- Shaper
- Planer
- Slotter

The main characteristics of this class of machine tools are that they are simple in construction and, as a result, are very economical in operation.

10.2.1 Shaper

The shaper is a relatively slow machine tool with very low metal removal capability. Hence it is being replaced by the more versatile milling machine in many shops. This is a low cost machine tool and hence is used for initial rough machining of the blanks. It is rarely used in production operations.

It uses a single point tool similar to a lathe which is clamped to a tool post mounted to a clapper box, which in turn is mounted to a reciprocating ram, as shown in Figure 10-2. The ram, while undertaking the cutting stroke, pushes the cutting tool through the workpiece to remove the material. When the ram returns, no cutting takes place. In between the return and cutting strokes, the table moves in the horizontal direction perpendicular to the cutting direction, which is termed as the feed direction.

The single point cutting tool is clamped in the tool head as shown in Figure 10-2. The tool head has the ability to swivel the cutting tool in any angle while being able to clamp the tool with any overhang depending upon the requirement. The swivelling ability is important for the tool to machine surfaces that are not in horizontal plane. Further, the tool should be firmly supported during the forward motion to carry out the material removal. During the return stroke, the cutting tool will not be doing the cutting and hence this will be an idle stroke. If the tool is held firmly as in the cutting stroke, the tool will rub the already machined workpiece and, also, the flank surface of the tool will wear out quickly. To reduce this wear and tear, the tool is lifted during the return stroke by the clapper box arrangement.

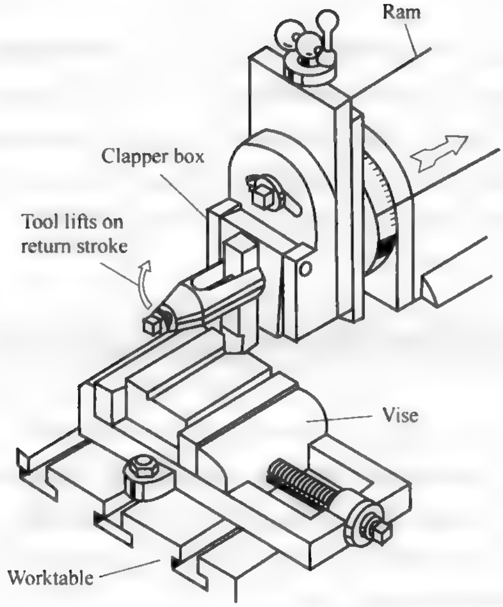


Figure 10-2 Typical arrangement of the workpiece and the tool ina shaper

A shaper is generally used for machining flat surfaces in horizontal, vertical and angular directions. It can also be used for machining convex and concave curved surfaces. The actual surface generated is by means of the linear motions of the cutting tool. The feed rate and the depth of cut are so arranged that the resultant surface is a flat surface.

10. 2. 2 Planer

Planer is very similar to the shaper in terms of the surfaces that can be generated. Generally, a planer is used for machining large workpieces, which cannot be held in the shaper. In the shaper, the cutting tool reciprocates during the cutting motion, while in the case of planer, the worktable reciprocates. Feeding motion in the planer is given to the cutting tool, which remains stationary during the cutting motion.

A typical planer is shown in Figure 10-3. The tool head in a construction similar to the clapper box of a shaper is mounted on the cross rail. The tool head can be moved along the cross rail for the feeding action while the depth of cut can be controlled by moving the tool downwards. As shown in Figure 10-3, it is possible to mount more than one tool head on the cross rail as well as on the columns on both sides, so that multiple surfaces can be completed simultaneously. This helps in reducing the total machining time since planing is a relatively slow operation like shaping. Similar to shapers, planers also can be mechanically or hydraulically driven.

10. 2. 3 Slotter

Slotter is basically a vertical axis shaper. Thus the workpieces, which cannot be conveniently held in shaper, can be machined in a slotter. Generally, keyways, splines, serrations, rectangular

grooves and similar shapes are machined in a slotting machine. The stroke of the ram is smaller in slotting machines than in shapers to account for the type of the work that is handled in them.

The types of tools used in a slotter are very similar to those in a shaper, except that the cutting actually takes place in the direction of cutting. However, in view of the type of surfaces that are possible in the case of slotter, a large variety of boring bars or single-point tools with long shanks are used.

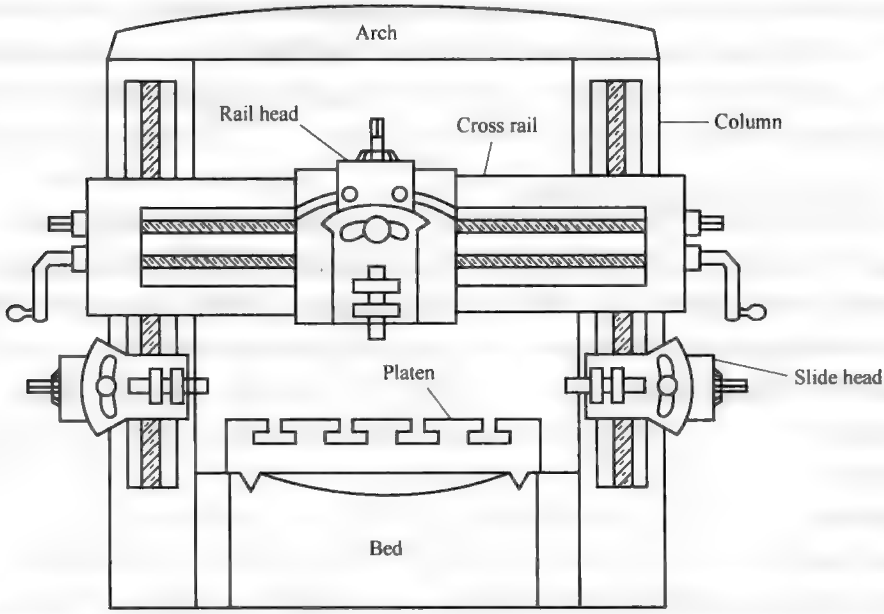


Figure 10-3 Construction of a planning machine

10.3 Milling Machines and Milling

Milling machine is a versatile machine tool that uses a rotating milling cutter while the workpiece reciprocates in contact with the cutting tool. After the class of lathes, milling machines are the most widely used for manufacturing application. In milling, the workpiece is fed into a rotating milling cutter, which is a multi-point tool, unlike a lathe, which uses a single point cutting tool. The tool used in milling is called milling cutter.

The milling process is characterized by features given below.

1. Interrupted Cutting

Each of the cutting edges removes material for only part of the rotation of the milling cutter. As a result, the cutting edge has time to cool before it removes material again. Thus the milling operation is cooler compared to the turning operation. This allows for larger material removal rates.

2. Small Size of Chips

Though the size of the chips is small, in view of the multiple cutting edges in contact, a large amount of material is removed and as a result the component is generally completed in a single pass

only, unlike the turning process which requires a large number of cuts for finishing.

3. Variation in Chip Thickness

This contributes to the non-steady state cyclic conditions of varying cutting forces during the contact of the cutting edge with the chip thickness varying from zero to maximum size, or vice versa. This cyclic variation of the force can excite any of the natural frequencies of the machine tool system and would be harmful to the tool life and surface finish generated.

Milling machine is one of the most versatile machine tools. It is adaptable for quantity production as well as in job shops and tool rooms. Versatility of the milling is due to the large variety of accessories and tools available with the milling machines. Typical tolerance expected from the process is about ±0.050mm.

10.3.1 Types of Milling Machines

To satisfy the variety of requirements as above, milling machines come in a number of ways, sizes and varieties. In view of the large material removal rates, the milling machines come with a very rigid spindle and large power. The varieties of milling machines available are:

1. Knee and Column Type

- Horizontal
- Vertical
- Universal
- Turret type

These are the general purpose milling machines, which have a high degree of flexibility and employed for all types of works, including batch manufacturing. A large variety of attachments to improve the flexibility are available for this class of milling machines.

2. Production (Bed) **Type**

- Simplex
- Duplex
- Triplex

These machines are generally meant for regular production involving large batch sizes. The flexibility is relatively less in these machines than suitable for productivity enhancement.

3. Plano Millers

These machines are used only for very large workpieces involving table travels in metres.

4. Special Type

- Rotary table
- Drum type
- Copy milling (Die sinking machines)
- Keyway milling machines
- Spline shaft milling machines

These machines are of a special class to provide special facilities to suit specific applications that are not catered by the other classes of milling machines.

10.3.2 Milling Operation

1. Clamps

For large and irregular workpieces, clamps in a variety of shapes are available. These clamps can be applied in a variety of ways. However, care has to be taken while the clamps are used for work holding. The workpiece should not be shifted under the action of the cutting forces. Also the clamping force should not be too great so that the distortion of the workpiece does not take place.

2. Milling Setups

Depending upon the situation, a large variety of milling methods have been developed in view of its versatility. They are described below, more as a convention being followed in the shop floor rather than based on any other scientific basis.

(1) String milling. In string milling, small workpieces which are to be milled, are fed into the milling cutter one after the other. In other words a number of workpieces will be kept on the machine table in a line and hence this method is called as "string milling" or "line milling". The main advantage is that if individual workpieces are milled, the milling cutter will have to have the approach distance, which is substantial. By having a number of workpieces kept in line, the approach distance will be only at the beginning and end of the line, thus considerably saving the machine time.

(2) Abreast or reciprocal milling. This is an operation done with special milling fixtures, which have a capability for indexing 180°. While one component is being machined at position 1 the second component will be loaded at the second position which is at 180° to the first one. When the machining is completed at position 1, the fixture indexes bringing the already clamped component ready for machining. In this case, the machine need not remain idle during the unloading, loading and setup of the blank for machining.

(3) Rotary or circular milling. Rotary milling takes the reciprocal milling to a greater length. A number of fixtures depending upon their size are located on a rotary table such that a number of workpieces can be loaded simultaneously on the machine table. This will save the setting time of the workpieces and keeps the machine cutting all the time except during the indexing of the rotary table. The rotary fixture can be integral with the milling machine or a separate accessory fixed to the milling machine table.

(4) Gang milling. In gang milling, a number of milling cutters are fastened to the arbour to suit the profile of the workpiece to be machined. For example two side and face milling cutters with a slab milling cutter at the centre are used to mill an inverted U-shape. The advantage of gang milling is that several surfaces are machined at the same time. It is also possible to combine form cutters along with the general purpose cutters.

One of the major problems is the choice of the cutting speed, which is determined by the largest cutter diameter. Hence it is desirable that all the cutters should be similar in size and shape to allow for larger speeds and feeds. In production milling operations, gang milling is more generally preferred.

(5) Straddle milling. Straddle milling is a special form of gang milling where only side-and face-milling cutters are used.

10.4 Hole Making Operations

Practically all components have some holes that need to be completed before the part can be used. Thus hole making operations are an important part of a machine shop.

Machining round holes in metal stock is one of the most common operations in the manufacturing industry. It is estimated that out of all the machining operations carried out, about 20% are hole making operations. Usually, no workpiece will leave the machine shop without having a hole made in it. The various types of holes are shown in Figure 10-4.

The types of hole-making operations performed on these holes are: drilling, boring, reaming, counter sinking, counter boring and tapping. Whereas drilling is used for making a hole in solid material, all the other operations are used to enlarge the hole or improve the quality of the hole depending upon the requirement.

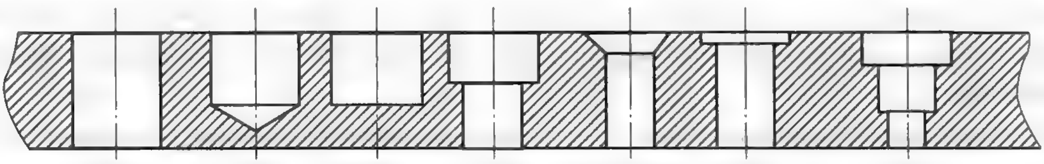


Figure 10-4 Various types of holes

10.4.1 Drilling

1. Types of Drills

A large variety of drills are developed, in addition to the standard twist drill, to be used for specific applications.

(1) Oil hole drills. These are most useful for deep hole drilling. These are provided with two internal holes extending through the length of the drill through which the cutting fluid can be pumped under pressure. This keeps the cutting edge cool while flushing away the chips as well.

(2) Step drills. A variety of step drills are developed to be suitable for combination machining of operations, such as multiple-hole drilling, counter boring and counter sinking.

(3) Core drills. These are special drills meant for enlarging already existing holes such as those needed in castings. They are either three- flute or four-flute type. The four-flute type is used for enlarging the drilled holes, while the three-flute type is used for punched or cored holes. The three-flute type keeps the chatter to a minimum due to the fact that the cutting lips are not diametrically opposite to each other. ②

(4) Shell core drills. These are similar to the core drills, but do not have a normal shank for the purpose of holding. They are used to make holes with large diameters. These drills need to be mounted using a stub arbor similar to the shell end mills with the help of the central hole present.

(5) Spade drills. Spade drills are used to make holes with smaller diameter using low cutting speeds and high feed rates. These have long supporting bar with the cutting blade attached at the end. These are less expensive since the support structure can be made more rigid using ordinary steel with no spiral flutes. Spade drills are also used to machine small conical shapes for subsequent drilling or making a bevel (similar to countersinking) on the existing holes to facilitate the subsequent tapping and assembling operations.

(6) Carbide tipped drills. Most of the drills are made of high speed steel. However, for machining hard materials as well as for large volume production, tungsten carbide tipped drills are available. The tungsten carbide tips of suitable geometry are clamped to the end of the tool to act as the cutting edges. Coating on the cutting tool provides a better alternative in improving the cutting tool life. This applies to the case of a high speed steel drill. The titanium nitride (TiN) coating on the drills is improving the drill tool life on an average by 2 to 10 times while drilling steel.

2. Gun Drilling

Gun drilling is the process of drilling extremely long or deep holes, and was originally developed for making the gun barrels, from which it derives its name. This process is widely applied to produce precision long and short holes up to 200mm diameter and 30m length. A typical gun drill consists of a hollow tube with a V-shaped groove or flute along its length, with a carbide cutting tip which also acts as its own guide bushing as it drills the hole, as shown in Figure 10-5. A gun dill can produce holes up to 100 times its diameter. The success in gun drilling is achieved by choosing suitable speeds and feeds which facilitate proper chip management, and adequate coolant pressure for lubrication of the brazed carbide tip along with the chip evacuation through the drill's single flute. High-pressure oil or water-soluble coolant flows through an internal coolant passage of the gun drill to the cutting area.

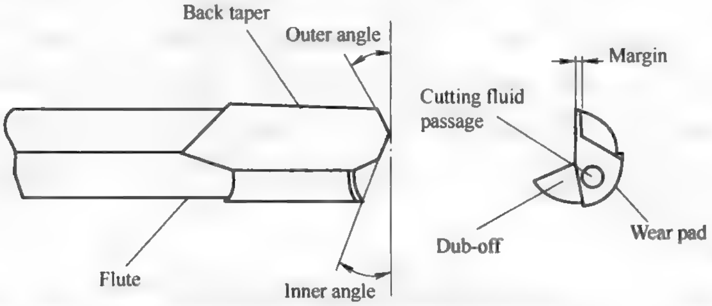


Figure 10-5 Schematic diagram of a gun drill

Cutting fluid forces the chips formed by the cutting action up the flute and out of the hole. The high-pressure (140MPa or higher) coolant system includes chip separation and filtration units to maintain clean coolant. If not done properly, chips in the coolant directed to the tool will impair its function and clog small drills. Drilling action is taking place off the centre point and, as a result,

considerable pressure acts on the wear pad that is used to help guide the drill and create a burnishing effect as the hole is drilled. ③ Typical surface finish of a gun-drilled hole is from 0. 8 to 1. 5 μm. Rotate the tool instead of the work wherever feasible. Gun-drilling machines in which the work rotates are more sensitive to misalignment than those in which the tool is rotated. Gun-drilling machines should have the highest rigidity to provide accurate alignment.

10. 4. 2 Reaming

1. Reamer

Reamer is a multi-tooth cutter, which rotates and moves linearly into an already existing hole. The previous operation could have been drilling or preferably boring. Reaming will provide smooth surface as well as close tolerance on the diameter of the hole. Generally, the reamer follows the already existing hole and therefore will not be able to correct the hole misalignment.

A reamer is more like a form tool, since the cylindrical shape and size of the reamer is reproduced in the hole. In reaming, very little material is removed. At the bottom of the reamer, the flutes (cutting edges) are made slightly tapered to facilitate its entry into the existing hole. Generally, the reamer is expected to cut from the sides and not from the end. Reamers are most suitable for reaming through holes. However, for reaming blind holes with flat bottom, special end-cutting reamers that look similar to end mills will have to be used. They have the cutting edges also formed at the end.

The reamer flutes are either straight or helical. The helical flutes promote smoother cutting and should be used specifically for holes that are not continuous, such as those with keyways parallel to the axis of the hole. The cutting action of the helical flutes is smoother and helps in preventing chatter, which is likely to occur in view of the large area of contact between the tool and the workpiece.

The reamers are termed as left hand or right hand, depending upon the direction in which they are moved, looking from the shank to the cutting portion. Also, if the reamer, as it is rotated to the right and it advances towards the cutting portion then it is termed as the right-hand helix. The reverse is termed as the left-hand helix. The right-hand reamer with right-hand helix is used for roughing cuts, since the tool tends to go into the workpiece more efficiently and thereby promotes the material removal. Similarly, a right-hand reamer with left-hand flutes is used for finishing cuts.

Since the reamer follows the already existing hole, any misalignment present in the hole is likely to break the reamer if mounted in the conventional spindle. Hence, a floating reamer holder is used between the machine spindle and the reamer to adjust for any small misalignment between the spindle axis and hole axis.

2. Reaming

The cutting speeds used in reaming are relatively small and the feeds generally large compared to an equivalent drilling operation to assure the required surface finish. Suggested cutting speeds are given in Table 10-1.

Chatter is often caused in reaming due to the lack of rigidity in the operation. To reduce the chatter, reduce the cutting speed, increase the feed rate, add a chamfer to the hole being reamed to facilitate the easier entrance of the reamer, or use a reamer with a pilot. The workpiece should be

properly supported during the reaming operation; otherwise oversized holes will be produced. If the reamer axis is misaligned with the axis of the hole, a bell-mouthed hole will result.

Table 10-1 Cutting speeds for reaming

Work Material	Cutting Speed, m/min
Aluminum and its alloys	45 - 70
Brass	45 - 70
Bronze	15 - 20
Cast iron, Soft	20 - 35
Cast iron, Hard	15 - 20
Steel Low carbon	15 - 20
Steel Medium carbon	12 - 15
Steel High carbon	10 - 12
Steel Alloy	10 - 12
Stainless steel	5 - 20

10.4.3 Boring

Boring is an operation of enlarging a hole. Generally, the single-point tool bit is mounted in the boring bar of suitable diameter commensurate with the diameter to be bored. The overhang of the tool is to be maintained as small as possible to reduce the chatter, which is very common in boring.

The workpiece where a hole is already existing, is mounted on the table of a horizontal boring machine. The table of a horizontal boring machine (Figure 10-6) has accurate guideways to move the table in two perpendicular directions (X and Y in horizontal plane). Generally heavy workpieces and heavy bores, which are difficult to be handled in the drilling machines are bored in horizontal boring machines. A drilled hole, which is not properly located, can be made concentric with the axis of rotation of the spindle by the boring operation.

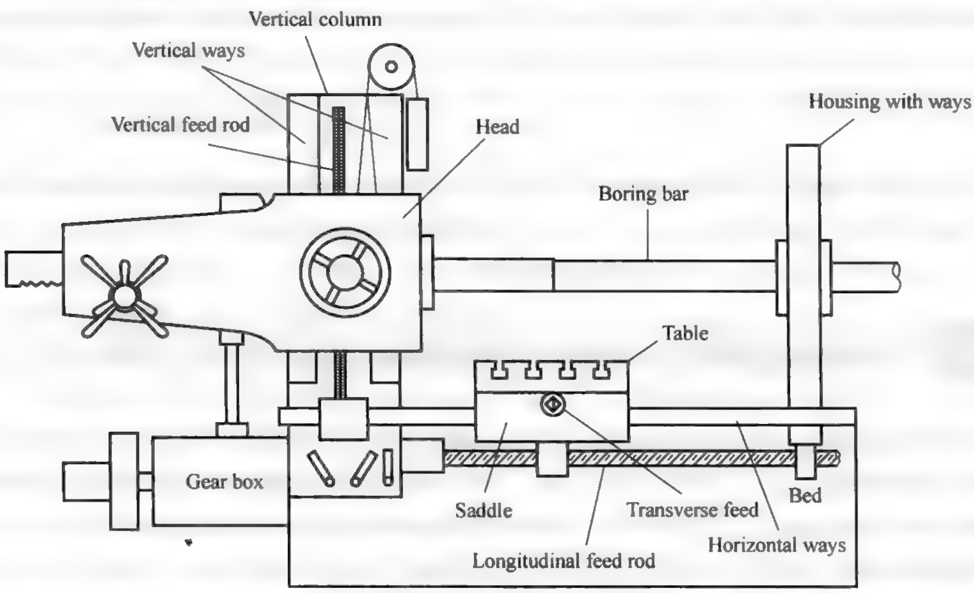


Figure 10-6 Horizontal boring machine

It is also possible to carry out the boring operation in a lathe for limited applications, while in drilling and milling machines, a large range of holes can be bored using the multiple-point cutting tools in addition to the single-point tool. Boring with a single-point cutting tool, being a semi-finishing operation, very small amount of stock is left out to be removed.

A major problem of boring with a boring bar with single-point turning tool is lack of rigidity of the boring bar. The size of boring bar is dictated by the size of the hole to be bored, while its length depends upon the geometry of the bore. Typically, up to a length of boring bar equal to 5 times the diameter of the bar, simple boring bars would be able to serve the purpose. However beyond this length, chatter becomes predominant, reducing the finish of the bore produced. It is necessary to use special damped boring bars for boring bars above this range.

10.4.4 Tapping

A faster way of producing internal holes is by the use of tapping operation. A tap is a mult-fluted cutting tool with cutting edges on each blade resembling the shape of threads to be cut. A tap is to be used after carrying out the predrilling operation corresponding to the required size.

The cutting edges being of the same shape as that of the thread to be machined, the helical angle forces the chips to be moved ahead through the flutes. The flutes therefore are straight, increasing the strength of the tap.

Tap is basically a form tool and therefore care has to be taken while regrinding to maintain the form as well as dimensions. While tapping, care has to be taken to see that the tap is started in proper alignment with the hole. Once started, the tap is automatically drawn into the hole by the threads and hence it should not be forced in. Sometimes it may become necessary to reverse the tap slightly to break the chips and clear the chip space and then continue in the normal way. Use of copious quantity of cutting fluid is essential, since tapping is heavy and slows material removal operation.

Tapping speeds used are generally smaller compared to drilling in view of the large feeds that are used. The speed need to be lowered as the length of the hole increases because of the problem of the chip removal and their potential ability to get welded to the tap, thereby reducing its cutting ability.

For machine tapping, the tap should be held in a floating holder to allow for sufficient flexibility for the tap to follow the existing hole. The tap should be rotated in the reverse direction to extract it from the hole after completing the tapping operation.

10.5 Grinding and Abrasive Processes

Abrasive processes utilize very small abrasive grains to remove material to provide good finish on metallic parts. Grinding is a process carried out with a grinding wheel made up of abrasive gains for removing very fine quantities of material from the workpiece surface. The required size of abrasive grains are thoroughly mixed with the bonding material and then pressed into a disc shape of given diameter and thickness. This can be compared to a milling process with an infinite number of cutting

edges.

Grinding is a process used when following features are needed:

1) Machining materials which are too hard for other machining processes such as tool and die steels, and hardened steel materials.

2) Close dimensional accuracy of the order of 0.3 to 0.5μm.

3) High degree of surface smoothness such as Ra = 0.15 to 1.25μm.

Grinding accounts for 25% of all the machining processes used for roughing and finishing processes. The characteristics of some of the abrasive processes are given in Table 10-2.

Table 10-2 Characteristics of various abrasive processes

Process	Particle Mounting	Features
Grinding	Bonded	Wheels, generally for finishing; Low material removal rate
Creep feed grinding	Bonded open soft	Wheels, slow feed and large depth of cut
Snagging	Bonded, Belted	High material removal rate, roughing to clean and deburr castings and forgings
Honing	Bonded	Stones contain fine abrasives for hole finishing
Lapping	Free	For super finishing

The abrasive grains are basically spherical in shape with large sharp points, which act as cutting edges. All the grains are of random orientations, and as such, the rake angle presented to the work material can vary from positive to a large negative value. Many a grit also slide rather than cut because of its orientation.

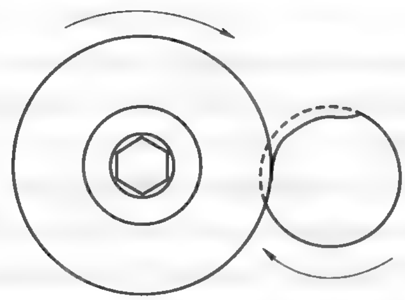
The depth of cut taken by each of the grain is very small. However, a large number of grits are acting simultaneously and hence the material removed is large. Also, cutting speeds employed are large. Chips produced as a result are very small and are red hot. Often they get welded easily to the abrasive grain or to the workpiece. Thus, the grinding process is inefficient compared to the conventional metal cutting processes.

10.5.1 Types of Grinding

Grinding operations are generally classified based on the type of surface produced. The grinding operations possible can be classified as given below.

- Cylindrical grinding for generating cylindrical surfaces.
- Surface grinding for generating flat surfaces.
- Centreless grinding for generating axisymmetric shapes.

The cylindrical grinding machine is used generally for producing external cylindrical surfaces. The machine is very similar to a centre lathe. The grinding wheel is located in a way similar to the tool post with an independent power, and is driven at high speed suitable for grinding operation. Both the work and the grinding wheel rotate counterclockwise. The work that is normally held between centres is rotated at much lower speed compared to that of the grinding wheel as shown in Figure 10-7.



igure 10-7 Relative motions of grinding wheel and the work in the cylindrical grinding operation

If the finished section to be ground is wider than the wheel, the wheel is fed in the transverse direction. Plunge grinding is done if the part is the same size as or less than the width of the wheel. Very fine finishes are obtained with cylindrical grinding. It is possible to get accuracies to within 0. 25μm with extreme care. Workpieces are normally mounted between centres and are driven by a dog. If necessary, the work should be supported by work-rests, placed on opposite side of the wheel to prevent deflection.

The traverse feed of the workpiece past the grinding wheel is provided by using a hydraulic arrangement. In feed is provided by the movement of the grinding wheel head into the workpiece. Economical grinding allowances that can be left are about 0. 1 to 0. 3mm.

10. 5. 2 Basic Abrasive Processes

1. Honing

Honing is a low abrading process using bonded abrasive sticks for removing stock from metallic and non-metallic surfaces. However, it can also be used for external cylindrical surfaces as well as flat surface for which it is rarely used. It is most commonly used for internal surfaces. This is an operations performed as the final operation to correct the errors that resulted from the previous machining operations. The characteristics that can be achieved by the honing process are: correction of geometrical accuracy, out-of-roundness, taper, axial distortion and dimensional accuracy.

Abrasive grains are bonded in the form of sticks by a vitreous or resin material and the sticks are presented to the work so that their full cutting forces are in contact with the work surfaces. Since a large number of abrasive grains are presented to the work surface simultaneously, substantial material removal takes place.

The abrasive grains put more pressure on the high spots. After the crests are removed, the bore is made straight. Since a large number of grains are in contact with the total surface, uniform surface finish is obtained. Also, the honing force and temperature are never concentrated at any one point. This results in less surface damage compared to other machining processes.

All materials can be honed. However, the material removal rate is affected by the hardness of the work material. Maximum bore size that can be conveniently honed is about 1, 500 mm while the minimum size is 1. 5mm in diameter. Honing allowance should be small to be economical. However, the amount also depends upon the previous error to be corrected.

Abrasive and the grain size to be selected depends upon the work material and the resultant finish desired. Generally higher cutting speeds are used for metals that shear easily, such as cast iron and non-ferrous metals. Alternatively, the harder workpieces require lower cutting speeds. Also, the rough surfaces that dress the honing stone mechanically allow higher cutting speeds. Speeds should be decreased as the area of abrasive grain per unit area of bore increases. Higher cutting speeds usually result in finer finish. However, they cause decrease in dimensional accuracy, overheating of workpiece and dulling of the abrasive.

2. Lapping

Lapping is generally the final finishing operation done with loose abrasive grains. The process is employed to get the following characteristics.

1) Extreme accuracy of dimension.

2) Correction of minor imperfection of shape.

3) Refinement of surface finish.

4) Close fit between mating surfaces.

The service life of components which are in close contact during machining can be greatly increased by the lapping process which removes the valleys and hills present on the machined surfaces. Lapping can be carried out on fiat surfaces as well as any other forms such as cylindrical or any form surfaces. The lap has to match the form surface required.

Stock removal rates with silicon carbide are generally more compared to aluminum oxide. Correspondingly, aluminum oxide gives better surface finish for the same grain size. Softer non-ferrous materials require a finer grain size to produce satisfactory finish comparable with those produced on steel.

Lapping is done by charging a lap made of soft material with abrasive particles and rubbing it over the workpiece surface with a slight pressure. Lapping is done manually or by specially designed machines. Pressure is applied on the lap which is moved with the loose abrasive between the lap and the work, removing the material from the work till the work conforms to the profile of the lap. The surface produced is dull in view of the random scratched pattern. Lap materials generally used are cast iron, soft steel, bronze and brass.

In order to achieve uniform abrasion of the work surface, it is necessary to ensure that all the points on the work are subjected to the same amount of abrading by careful manipulation of the lap.

Special lubricants generally called vehicles are used during the lapping process. The desirable properties of fluids used as vehicles are:

1) Abrasive should be held in uniform suspension during the operation.

2) It should not evaporate easily.

3) It should be non-corrosive.

4) It can be easily removed by normal cleaning.

The materials which satisfy the above criteria are water soluble cutting fluids, vegetable oils, mineral oils and greases.

Lapping speed is 100 to 250m/min. The material removed depends upon the lapping

speed. Higher lapping allowances require higher lapping speeds. The lapping pressure applied is 0.01 to 0.03MPa for soft materials and 0.07MPa for hard materials. Higher pressures are likely to cause scouring of the work surface. Lapping allowance depends on the previous operation carried and the material hardness.

3. Super Finishing

Super finishing is another abrasive process utilizing either a bonded abrasive like honing for cylindrical surfaces or a cup wheel for flat surfaces. It is generally used for the following functions.

1) It removes surface fragmentation.

2) It reduces surface stresses and burns and thus restores surface integrity.

3) It corrects inequalities in geometry.

4) It also produces high wear resistant surface on any object which is symmetrical. Typical surfaces that are super finished are cylindrical, flat, conical and spherical.

Contact surface in super finishing is large and the tool maintains a rotary contact with the workpiece while oscillating, as shown in Figure 10-8. The typical stroke of the super finishing stone is about 1 to 5mm with an oscillating frequency of 2kHz. Super finishing speeds used are 10 to 40m/min while the working pressure maintained is about 0.1 to 0.3MPa. The heat generated under these conditions is appreciably small and hence no metallurgical alteration of the work. The finish obtained on the surface depends upon the time for which the stone is in contact with the work.

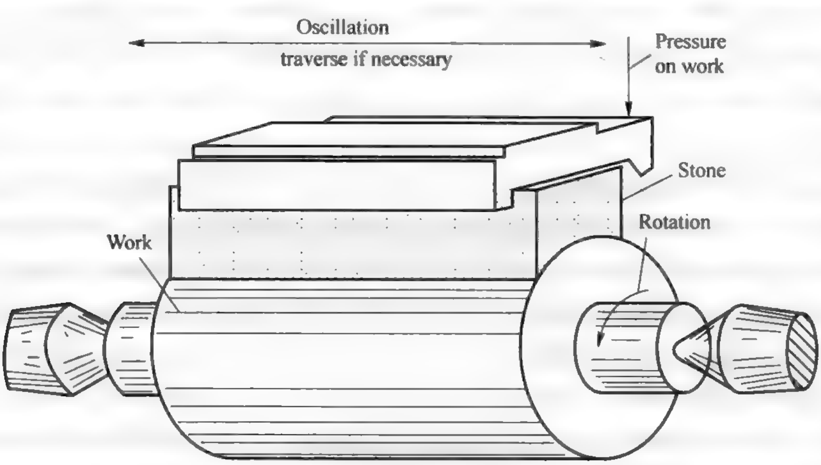


Figure 10-8 Typical motions in super finishing operation

4. Polishing and Buffing

Both these processes are used for making the surfaces smoother, as well as giving a glossy finish. Polishing and buffing wheels are made of cloth, felt or similar materials, which are soft and have a cushioning effect. Polishing is done with a very fine abrasive which is used in loose form and is smeared on the polishing wheel with the work rubbing against the flexible wheel. [4] A very small amount of material is removed in polishing. In buffing, the abrasive grains in a suitable carrying medium, such as grease, are applied at suitable intervals to the buffing wheel. Negligible amount of material is removed in buffing while a very high luster is generated on the buffed surface. The dimen-

sional accuracy of the parts is not affected by the polishing and buffing operations.

5. Abrasive Belt Grinding

In this process, a continuous moving belt with an abrasive is used for grinding the surfaces. The abrasive belt is normally passed between two wheels, with one being driven while the other is idling. Use of abrasive belts results in cooler cutting and rapid material removal rates as compared to conventional grinding. The workpiece is oscillated across the face of the abrasive belt to obtain a uniform belt wear and surface finish.

This method is most suitable for flat surfaces. However, cylindrical surfaces can also be belt ground by using a suitable contact wheel. Abrasive belt with a very fine grit may be used for polishing application.

10.6 Sawing and Broaching

In addition to the various general purpose machines tools that were discussed so far, a few more machine tools which are used for very specific application, but not necessarily in the mainstream of the manufacturing activity, are discussed in this section.

10.6.1 Sawing

Sawing is one of the basic machining operation carried out in a narrow cutting zone through the successive removal of chips by the teeth on a saw blade. The teeth represent the cutting edges. Each of the teeth removes a part of the chip, which is contained in the chip space of the saw blade, till the tooth comes out of the material as shown in Figure 10-9.

Sawing is one of the most economical processes because there is removal of very small amount of material, as it consumes less power and at the same time is able to cut large sections. The process can be very easily automated thereby reducing the labour cost involved as well.

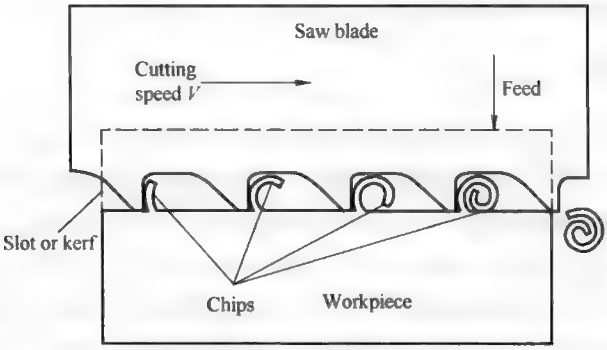


Figure 10-9 Saw blade in action

The various types of sawing machines used are the following:

- Hack saw: Manual and Power
- Band saw: Vertical, Horizontal, and Contour

- Circular saw

1. Power hack saw

The power hack saw uses the hack saw blade. The blade is mounted in the hack saw frame and reciprocated for the sawing operation. These are very simple machines with a tool frame for holding the saw and some work-holding device similar to a vice. ⑤ The reciprocating motion is inherently inefficient because no cutting can take place during the return stroke.

2. Band saw

These basically have a continuous band of saw blade rotated between two disks such that the cutting action will be continuous unlike the power hack saw. These are generally used for cutting off single stationary workpieces that can be held on to the table of the band saw. The saw blade call be tilted up to 45° to permit cutting at any angle.

The band saw operates continuously such that the cutting force is always directed against the table. This is relatively safer compared to the hack saw and can cut workpieces without even clamping them to the table.

Contour band saw machines are similar to band sawing machines and are used for sawing of any predefined contours in the workpiece. The contour need not start from the edge of the workpiece, but can start at any point inside the workpiece. In these machines, the saw band can be broken and then inserted through a predrilled hole in the workpiece. The blade is then butt-welded into a continuous circle and sawing completed. After completing the sawing operation, the band is again broken to remove the workpiece and the cycle continued. Also, these bands have swivel tables which permit angular cutting required for die blocks. These machines are equipped with flash butt welder, annealing and grinding units for the purpose of welding the saw blade. ⑥

3. Circular saw

These have the ability to run the saw at very high cutting speeds unto about 130m/s and large feed rates. The stock can be cut very quickly and, therefore, care has to be taken for the selection of the parameters to maximize the productivity.

10.6.2 Broaching

Broaching is a multiple-tooth cutting operation with the tool reciprocating, similar to sawing operation described earlier. The similarities end there, since in broaching the machining operation is completed in a single-stroke as the teeth on the cutting tool, called broach, are at gradually increasing height corresponding to the feed per tooth of a milling cutter.

There are basically four different types of broaching machines: push broaching machines, pull broaching machines, surface broaching machines, and continuous surface broaching machines.

1. Push Broaching Machines

These are generally used for internal surfaces where the broach movement is guided by a ram. These machines are simple, since the broach only needs to be pushed through the component for cutting and then retracted. The workpiece is fixed into a boring fixture on the table. Even simple arbor presses can be used for push broaching.

2. Pull Broaching Machines

These are a little more complex in terms of operation. These consist of a work-holding mechanism, broach-pulling mechanism, along with a broach elevator to help in the removal and threading of the broach through the workpiece. The workpiece is mounted in the broaching fixture and the broach is inserted through the hole present in the workpiece. Then the broach is pulled through the workpiece completely, after which the workpiece is removed from the table. The broach is then brought back to the starting point before a new workpiece is located on the table. The same cycle is repeated.

The power for the pulling mechanism and the movement of the broach are provided by hydraulic fluid. Because of the inner surface broaching, it is necessary to remove the broach from the pulling mechanism to thread it through the workpiece hole in every cycle.

3. Surface Broaching Machines

Surface broaching is relatively simple since the broach can be continuously held and then it will carry out only a reciprocating action. The workpiece is held in the fixture while the surface broach is reciprocated with the ram on the vertical guideways on the column. The progressive action reduces the maximum broaching force, but results in a longer broach.

4. Continuous Surface Broaching Machines

The reciprocation of the broach always involves an unproductive return stroke, which is eliminated in a continuous surface broaching machine. In this the small workpieces are mounted on the broaching fixtures which are in turn fixed to a continuously moving conveyor as shown in Figure 10-10. Broaches, which are normally stationary, are kept above the workpieces. The workpieces are pushed past the stationary broaches by means of the conveyor for cutting. The workpieces can be loaded and unloaded onto the conveyor manually or automatically. These machines are used for mass production.

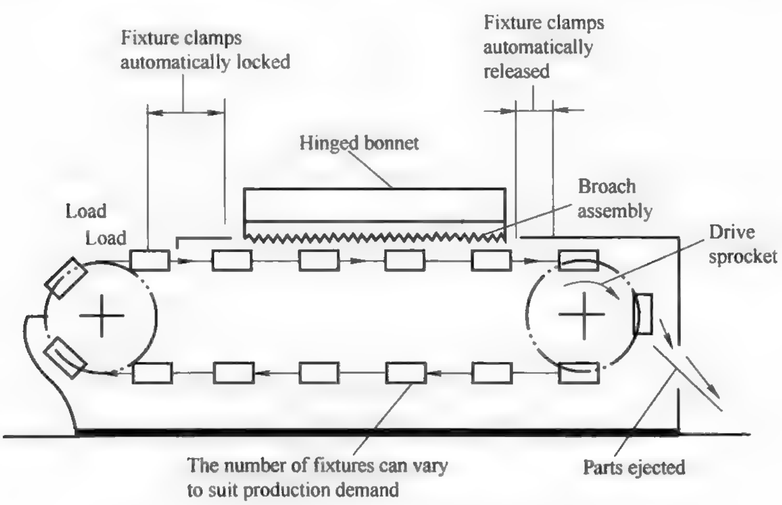


Figure 10-10 Continuous surface broaching machine

(From *Manufacturing Technology* by P. N. Rao)

难句释义

① due care 意为“应有的注意”，also 意为“因此”。全句译为：因此，当选择工件的转速时，应该考虑到这个问题（即上文提到的问题）。

② cutting lip 意为“刀刃”，此处译为“钻刃”；diametrically 意为“直径方向地，径向地”。全句译为：三钻槽式钻头可以将振动降到最低，因为各钻刃之间在直径方向上不是相对排列的。

③ 全句译为：钻孔作用偏离中心，因此会给引导钻头的垫磨片上施加一定的压力，从而在钻孔过程中产生抛光的效果。

④ 该句可结合上文，分为两部分理解，一部分为抛光轮的制作，一部分为抛光加工的过程。全句译为：非常细的研磨颗粒以松散的方式涂抹到抛光轮上，工件与柔性抛光轮摩擦实现抛光。

⑤ vice 此处意为“虎钳”。全句译为：电动弓锯床是非常简单的机器，装有夹持弓锯的机架和类似于虎钳的工件夹持装置。

⑥ flash butt welder 意为“闪光对焊机”。全句译为：这些机器装配有闪光对焊机、退火及磨削装置，用来焊接锯条。

Unit 11

Robots

11.1 Introduction to Robots

The subject of "Robotics" is relevant in today's engineering curriculum because of the robots' ability to perform the tireless and dangerous jobs. A robot is only meaningful when it is meant to relieve a human worker from doing a boring, unpleasant, hazardous, or a too precise job. A robot is normally designed to assist a human worker. In contrast to the general belief, a robot is actually not as fast as humans in most of the applications. It however, maintains its speed over a very long period of time. As a result, the productivity increases if the number of pieces to be produced are very large. Moreover, the intelligence of today's most advanced robot is nowhere near human intelligence. Thus, the introduction of a robot without a real understanding of its benefits will be disastrous and is not advisable.

11.1.1 History

Even though the idea of robots goes back to ancient times of over 3, 000 years ago in India's legend of mechanical elephants (Fuller, 1999), the first use of the word robot appeared in 1921 in the play *Rossum's Universal Robots* (*RUR*) written by the Czeck writer Karel Capek (1890 – 1938). In the play *RUR* (Dorf, 1988), a fictional manufacturer of mechanical creatures designed robot to replace human workers. Efficient but totally lacking in emotions, these robots were first thought to be an improvement over the human beings since they did as they were told without a question. [1] These robots eventually turned on their masters. They destroyed the human race, save one man, such that he could continue to produce more robots. The formula, that was unfortunately, had been lost in the destruction wreaked by the robots.

The feeling of hatred towards robots seems to exist even today. The fear that robots will take away people's jobs might have resulted in the retardation of development in this area. However, Isaac Asimov in his science fiction stories during the 1940's envisioned the robot as a helper of humankind and postulated three basic rules for robots. These are generally known as the laws of robotics:

1) A robot must not harm a human being, nor through inaction allow one to come to harm.
2) A robot must always obey human beings, unless that is in conflict with the first law.
3) A robot must protect from harm, unless that is in conflict with the first two laws.

4) A fourth law was later introduced by Fuller (1999), which was stated as a robot may take a human being's job but it may not leave that person jobless.

Attempts are being made to adhere to these laws of robotics, but there are no automatic ways for implementing them. For instance, the military robot, by its very nature, is likely to be designed with the intention of breaking these laws. Most industrial robots of today are designed to work in environments which are not safe and very difficult for human workers. For example, a robot's hand can be designed to handle a very hot or a very cold object that the human hand cannot handle safely. Inspired by Asimov's books on robots, Joseph F. Engelberger tried to design a working robot in the 1950's. He, along with George C. Devol, started the UNIMATION Robotics Company in the USA in 1958. The first Unimate robot, however, was installed in 1961 in General Motor's automobile factory in New Jersey, USA. It was an automated die-casting mould that dropped red-hot door handles and other such car parts into pools of cooling liquid on a line that moved them along to the workers for trimming and buffing. Its most distinct feature was a grip on a steel armature that eliminated the need for a man to touch car parts just made from molten steel. It had 5 degrees of freedom (DOF), but there were a few applications in which a six DOF was required. Figure 11-1 shows such a Unimate robot.

Fig. 11-1 A Unimate robot

Since then robotics has evolved in a multitude of directions, starting from using them in welding, painting, in assembly, machine tool loading and unloading, inspection, agriculture, nursing purposes, medical surgery, military, security, machine-tools to undersea and space explorations. [2] A majority of them are still being used in welding (~25%) and assembly (~33%). The latest in the series are the Pathfinder Lander and the microrover, Sojourner, which landed on Mars on 4 July, 1997. They were developed by the National Aeronautic Society of America (NASA), USA.

11.1.2 Definition

A robot is formally defined in the International Standard of Organization (ISO) as a reprogrammable, multifunctional manipulator designed to move material, parts, tools or specialized devices through variable programmed motions for the performance of a variety of tasks. [3] There exist several other definitions too, given by other societies, e.g., by the Robotics Institute of America (RIA), The Japan Industrial Robot Association (JIRA), British Robot Association (BRA) and others. All

definitions have two points in common. They are reprogramability and multifunctionality of robots.

Robots are broadly classified as industrial and non-industrial or special-purpose. A typical industrial robot is shown in Figure. 11-2. Industrial robots are intend to serve as general purpose, unskilled or semi-skilled labour, e. g. for welding, painting, machining, etc. Alternatively, a special-purpose robot is the one that is used in other than a typical factory environment. For example, a serial robot mounted on a spacecraft used for retrieval of a faulty satellite or putting it back after repairs can be considered as a special-purpose robot. Other special-purpose robots are classified as follows:

Figure. 11-2 A typical industrial robot

(1) Automatic Guided Vehicles (AGVs). These are mobile robotic systems commonly used in factories for material handing purpose. Such AGVs generally follow a wire-guided path on the shop floors. There are also autonomous AGVs that do not require a wired path.

(2) Walking Robots. These robots walk like human beings. They are used in military, undersea exploration and places where rough terrains exist.

(3) Parallel Robots. As the name suggests, these robots have a parallel configuration, in contrast to the serial-like structure of an industrial robot. Such robots are also used as machine tools, and as medical robots to reduce the trembling of a surgeon's hand during an operation, etc. Figure. 11-3 shows the use of a parallel robot as a milling machine.

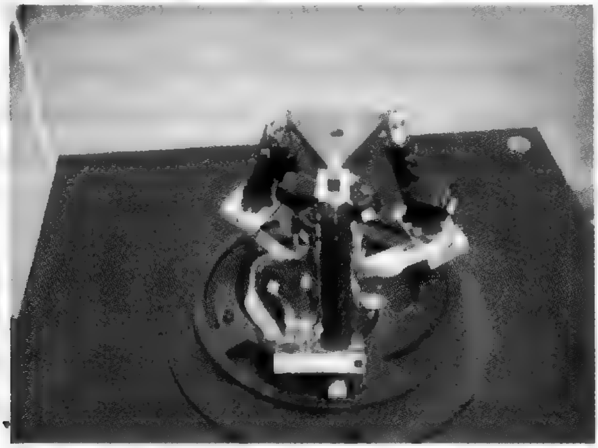


Figure. 11-3 A parallel robot used as a milling machine

11.1.3 Usages

Robots of any type, industrial or non-industrial, are neither as fast nor as efficient as the special-purpose automated machines. However, they can be easily retrained or reprogrammed to perform an array of different tasks, whereas an automated special-purpose machine, including a CNC machine, can perform only a very limited class of tasks. ④ It is the degree of re-programmability that differentiates a robot from a CNC machine tool. There is, however, no internationally recognized demarcation line. The question then remains when to consider whether a person, a robot, or a specializedmachine is to perform a certain job. The answer to this question is neither simple nor straightforward. Some thumb rules can help in suggesting some significant factors to be kept in mind.

1. Thumb Rules on the Decision of a Robot Usage

1) The first rule to consider is, what is known as the Four Ds of Robotics, i. e. is the task dirty, dull, dangerous, or difficult? If so, a human will probably not be able to do the job efficiently. Therefore, the job is appropriate for automation or for robotic.

2) The second rule is that a robot may not leave a human jobless. Robotics and automation must serve to make our lives more enjoyable, not miserable.

3) A third rule involves asking whether you can find people who are willing to do the job. If not, the job is a candidate for automation or robotics. Indeed this should be a primary reason for the growth of automation and robotics.

4) A fourth rule of thumb is that the use of robots or automation must make short-term and long-term economic sense.

So, as a general starting point, let us consider the following: A task that has to be done only once or a few times and is not dangerous is probably best done by a human. After all, a human is the most flexible of all machines. A task that has to be done a few hundred to a few hundred thousand times is probably better done by a flexible automated machine such as an industrial robot. Furthermore, a task that has to be done one million times or more is probably best handled by building a special-purpose hard-automated machine.

2. Applications

Throughout the world robots are most extensively and wildly used in the automobile industry. In recent times however, in addition to the automotive sector, strong demand from the electronic component industry, the communication equipment industry and the computer industry is reinforcing the gain of the market share. ⑤

3. Economics

Industrial robots are becoming cheaper and cheaper and is reflected in the used industrial robot prices. Consider that an ABB IRB 6000 that is priced at Rs. 3, 200, 000[⊖] cost over Rs. 7, 200, 000 when new in 1993. A new equivalent robot will cost between Rs. 2, 400, 000 to Rs. 4, 800, 000 depending on manufacturer and specifications. The prices of the robots are becoming so

⊖ Rs. 为货币单位卢比。

cheap that, for some countries, a new robot is even cheaper than the cheapest labourer.

4. Safety

Industrial robots can be dangerous. They are exceptionally powerful devices, especially models with a large capacity and reach. ⑥ This means that safety is paramount during the installation and during production. Safety guidelines vary from country to country and are essential to ensure that any installation complies with the local legislation. Mostly safety is about isolating personnel from the robot's work envelope and ensuring that the movements can be easily halted in an emergency. To this end robots have in-built dual safety chains or run-chains. ⑦ These are two parallel circuits that when broken will prevent the robot from moving. External connections including emergency stops are also catered for. It should also be noted that almost all robots have electrically operated disc brakes on each axis. These are on whenever power is not applied to release them. Therefore, in the event of a power failure or if the emergency stop is applied the robot stops dead, within a split second, in its position. It does not collapse and it retains positional and program data.

11.2 Robot Classifications

11.2.1 Classification by Application

As more and more robots are designed for specific tasks, this method of classification becomes more relevant. For example, many robots are designed for assembly work, which may not be readily adaptable for other applications. They are termed as 'assembly robots'. For seam welding, some suppliers provide complete welding systems with the robot, i.e. the welding equipment along with other material handling facilities like turntables etc. as an integrated unit. ⑧ Such an integrated robotic system is called a 'welding robot' even though its discrete manipulator unit could be adapted to a variety of tasks. Some robots are specifically designed for heavy load manipulation, and are labelled as 'heavy duty robots'.

11.2.2 Classification by Coordinate System

This classification is also referred to as a classification by the arm configuration and geometric work envelope. It actually classifies the arm of a robot without considering the wrist and hand. It tells the volume of reachable coordinates of a point on the end-effecter, rather than its orientations. These are four fundamental types, i.e. Cartesian, Cylindrical, Spherical or Polar, and Articulated or Revolute.

1. Cartesian

When the arm of a robot moves in a rectilinear mode, that is, in the directions of the x, y, and z coordinates of the rectangular right-handed Cartesian coordinate system, it is called a Cartesian or rectangular type. The associated robot is then called a Cartesian robot. The movements are referred to as travel x, height or elevation y, and reach z of the arm. Its workspace has the shape of a rectangular box or prism. A Cartesian robot needs a large volume space in which to operate. It has however, a

rigid structure and provides an accurate position of the end-effecter. Maintenance of such robots is difficult, as the rectilinear motions are generally obtained through sets of rotary electric actuators coupled with nut and ball screws. Hence, they have to be covered with bellows. Moreover, maintaining the straightness of the screw demands higher rigidity in those components. Hence, such robots tend to be more expensive.

2. Cylindrical

When the arm of a robot possesses one revolute and two prismatic joints, i. e. , the first prismatic joint of the Cartesian type, is replaced by a revolute one with its axis rotated by 90° about the reach z axis, the points that it can reach conveniently can be specified by the cylindrical coordinates, i. e. angle θ, height y, and radius z. A robot with this type of an arm is termed as a cylindrical robot whose arm moves by θ, y and z, i. e. it has a base rotation, an elevation, and the reach, respectively. Since the coordinates of the arm can assume any of the values between the specified upper and lower limits, its end-effector can move in a limited volume that is a cut section from the space between the two concentric cylinders. Note that for a Cartesian arm this is not the case. A robot of this type may have difficulties in touching the floor near the base. Cylindrical manipulators are successfully used when a task requires reaching into small openings or working on cylindrical surface, e. g. , welding two pipes.

3. Spherical or Polar

When the arm of a robot is capable of changing its configuration by moving its two revolute joints and one prismatic joint i. e. second prismatic joint along the height y of the cylindrical type is replaced by a revolute joint with its axis rotated by 90° about the reach z axis, the arm position is then conveniently described by the means of the spherical coordinates, θ, ϕ, and z. the arm is now termed as a spherical or a polar robot arm. The arm movements represent the base rotation, elevation angles, and reach, respectively.

4. Articulated or Revolute

When a robot arm consists of links connected by revolute joints only, i. e. the third prismatic joint of the spherical type is z axis, it is called an articulated or revolute jointed arm. Such robots are relatively simpler to fabricate and maintain, as the robot's actuators are directly coupled through a set of rotary gear or belt elements. However, achieving a task of the Cartesian coordinates requires mathematical transformation.

It is quite interesting to note that the above four fundamental arm architectures can be derived from one another. Some literatures also use the classification like Gantry and SCARA (Selective Compliance Assembly Robot Arm), respectively. This is truly not required, as the fundamental types are sufficient to help one to understand such types. For example, the arm in the gantry robot is of the Cartesian type, which is placed upside down. This robot is large, versatile in its operation, but expensive. The SCARA on the other hand, is a cylindrical type, whose reach is obtained by using a revolute, instead of a prismatic joint. A SCARA robot is very suitable for assembly operations and is therefore extensively used in several industries for this purpose.

11.2.3 Classification by Actuation

Robots are driven either by electric power or fluid power, the latter category being further subdivided into pneumatic and hydraulic. Today the most common drive method is electric with various types of motors e. g. stepper, DC servo, and brushless AC servo. Pneumatic robots are used in light assembly or packing work but are not usually suitable for heavy-duty tasks or where speed control is a necessity. On the other hand, hydraulic robots are used in heavy payload applications because of their high power to size ratios.

11.2.4 Classification by Control Method

Here control could mean two things, one is by its motion control strategy i. e. whether a robot is servo-controlled or not, the other one is how the motion path is achieved, i. e. point-to-point or continuous.

1. Servo/Non-servo Control

Robots are either servo-controlled (closed-loop) or non-servo controlled (open loop). To gain full advantage of the digital or microprocessor control, achieve good precision under heavy load conditions, and to carry out complex tasks with confidence, full servo-control is necessary. In this method of control, commands are sent to the arm drives to move each axis only the requisite amount. The actual movement is monitored for both the displacement and velocity and compared with the command signal. The difference between the command and the action, defined as the error, is used as a feedback to the controller to enable further commands to be modified accordingly. Most electric and hydraulic robots are servo-controlled.

Pneumatic robots are usually non-servo controlled. In this case, a command signal is sent and it is assumed that the robot arm reaches its intended position. Non-servo control is adequate where position control of light loads only is required. However if velocity, acceleration, and torque are to be controlled or if the movement against heavy loads is necessary then non-servo control is usually not possible. The majority of the industrial robots today are using servo-controls. This control problem requires knowledge of Proportional-Derivative (PD), Proportional-Integral (PI), Proportional-Integral-Derivative (PID), Fuzzy, Neural network, and other control theories.

2. Path Control

In a point-to-point path control, the robot arm moves from one desired point to the next without regard to the path taken between them. The actual path taken may be the result of a combination of arm link movements, calculated to provide the minimum travel time between the points. Point-to-point control is wildly used in assembly, palletising, and machine tool loading/unloading.

In a continuous path control, the robot moves along a continuous path with specified orientations for example, welding, where the signal from the sensors in the joints are constantly monitored by the robot controller. Such a control problem is referred to as a trajectory planning problem.

11.2.5 Classification by Programming Method

Industrial robots can be programmed by various means. For example, they can be programmed either online or offline. Online methods require the direct use of the robot and utilizes a teach pendant for point-to-point programming, and slave arms or a pistol grip attachment for a continuous path programming. More recent robots have the ability to be programmed offline i. e. , the robot can continue working on a particular task while a program for a new task is prepared on a computer terminal using the robot programming language, for example, VAL, ALU, and others.

11.3 Sensors

The major capabilities required by a robot are as follows:

1) Simple Touch: the presence or absence of an object.

2) Taction or Complex Touch: the presence of an object plus some information on its size and shape.

3) Simple Force: measured force along a single axis.

4) Complex Force: measured force along two or more axes.

5) Proximity : non-contact detection of an object.

6) Simple Vision: recognition of shapes.

For motion control, potentiometers, tacho-generators, encoders, etc. are used as joint sensors, whereas strain-gauge based sensing etc. , are used at the end-effector location for contact force control.

11.3.1 Internal Sensors

Internal sensors, as the name suggests are used to measure the internal state of a robot, i. e. its position, velocity, acceleration, etc. at particular instant. Based on these information, the control command is decided by the controller. Depending on the various quantities it measures, a sensor is termed as the position, velocity, acceleration, or force sensor.

1. Position Sensors

Position sensors measure the position of each joint i. e. the joint angle of a robot.

(1) Encoder. Encoder is a digital optical device that converts motion into a sequence of digital pulses. By counting a single bit or by decoding a set of bits, the pulses can be converted to relative or absolute measurements. Thus, encoders are of incremental or absolute type. Further, each type may be again linear and rotary.

1) Incremental linear encoder. The thickness of the grating lines and the gap between them is made equal, which is in the range of microns. On one side the scale is provided with a light source and a condenser lens. On the other side there are light sensitive cells. The resistance of the cells (photodiodes) decreases whenever a beam of light falls on them. Thus, a pulse is generated each time a beam of light is intersected by the opaque line. This pulse is fed to the controller, which up-

dates a counter (a record of the distance travelled).

2) Absolute linear encoder. It is similar in principle as the incremental linear encoder. The difference is that it gives an absolute value of the distance covered at any time. Thus, the chances of missing the pulses at high speeds are less. The output is digital in this case. If the opaque block represents 1 (one) and the transparent block as 0 (zero), then the left-most column will show a binary number as 00000, i. e. a decimal value of 0 and the next column will show a binary number 00001, i. e., a decimal value of 1.

3) Absolute rotary encoder. Similar to the absolute linear encoder, the circular disk is divided into a number of circular strips and each strip has definite arc segment. This sensor directly gives the digital output (absolute). The encoder is directly mounted on the motor shaft or with some gearing to enhance the accuracy of the measurement. To avoid noise in this encoder a gray scale is sometimes used. A gray code, unlike binary codes, allows only one of the binary bits in a code sequence to change between radial lines. It prevents confusing the changes in the binary output of the absolute encoder when the encoder oscillates between points.

(2) Potentiometer. Potentiometer, also referred to as simply "pot", is a variable resistance device that expresses linear or angular displacements in terms of voltage. It consists of a wiper that makes contact with a resistive element, and as this point of contact moves, the resistance between the wiper and end leads of the device changes in proportion to the displacement x and θ for linear and angular potentiometers, respectively.

(3) LVDT. The Linear Variable Differential Transformer (LVDT) is one of the most used displacement transducers, particularly when high accuracy is needed. It generates an AC signal whose magnitude is related to the displacement of a moving core. The basic concept is that of a ferrous core moving in a magnetic field, the field being produced in a manner similar to that of a standard transformer. There is a central core surrounded by two identical secondary coils and a primary coil. As the core changes its position with respect to the coils, it changes the magnetic field, and hence the voltage amplitude in the secondary coil changes as a linear function of the core displacement over a considerable segment. A Rotary Variable Differential Transformer (RVDT) operates under the same principle as the LVDT and is also available with a range of approximately $\pm 40°$.

(4) Synchros and resolvers. While encoders give the digital output, the synchros and resolvers provide analog signal as their output. They consist of a rotating shaft (rotor) and a stationary housing (stator). Their signals must be converted into the digital form through an analog to digital converter before the signal is fed to the computer.

2. Velocity Sensors

Velocity or speed sensors measure by consecutive position measurements at known time intervals and computing the time rate of change of the position values or directly finding it based on different principles.

(1) All position sensors. Basically, all position sensors when used with certain time bounds can give velocity, e. g. the number of pulses given by an incremental position encoder divided by the time consumed in doing so. But this scheme puts some computational load on the controller which

may be busy in some other computation.

(2) Tachometer. Such sensors can directly find the velocity at any instant of time, and without much of computational load. This measures the speed of rotation of an element. There are various types of tachometers in use but a simple design is based on the Fleming's rule, which states "the voltage produced is proportional to the rate of flux linkage" . Here, a conductor (basically a coil) is attached to the rotating element which rotates in a magnetic field (stator). As the speed of the shaft increases, the voltage produced at the coil terminals also increases.

(3) Hall-effect sensor. Another velocity measuring device is the Hall-Effect Sensor, whose principle is described next. If a flat piece of conductor material called the Hall chip is attached to a potential difference on its two opposite faces, then the voltage across the perpendicular faces is zero. ⑨ But if a magnetic field is imposed at right-angles to the conductor, the voltage is generated on the two other perpendicular faces. Higher the field value, higher is the voltage level. If one provides a ring magnet, the voltage produced is proportional to the speed of rotation of the magnet.

3. Acceleration Sensors

Similar to measurements of velocity from the information of the position sensors, one can find the accelerations as the time rate of change of velocities obtained from velocity sensors or calculated from the position information. But this is not an efficient way to calculate the acceleration because this will put a heavy computational load on the computer and that can hamper the speed of operation of the system. Another way to measure the acceleration is to measure the force which is the product of mass and acceleration. Forces are measured for example, using strain gauges. Then, the acceleration a, is the force divided by mass of the accelerating object m.

It is pointed out here that the velocities and accelerations that are measured using position sensors require differentiations. It is generally not desirable, as the noise in the measured data if any, will be amplified. Alternatively, the use of integrators to obtain the velocity from the acceleration, and consequently the positions are recommended. Integrators tend to suppress the noise.

4. Force Sensors

A spring balance is an example of a force sensor in which a force namely, the weight, is applied to the scale pan that causes a displacement, i. e. the spring stretches. ⑩ The displacement is then a measure of the force. There exist other types of force sensor, e. g. Strain gauge based, Hall-effect sensor, etc.

(1) Strain gauge. The principle of this sensor is that the elongation of a conductor increases its resistance. Typical resistance for strain gauge are 50 ~ 100Ω. The increase in resistance is due to increase in the length of the conductor and decrease in the area of the conductor.

Strain gauges are made of electrical conductors, usually of wire or foil, etched on a base material. They are glued on the surfaces where strains are to be measured. The strains cause changes in the resistances of the strain gauges, which are measured by attaching them to the Wheatstone bridge circuit as one of the four resistances. It is a cheap and accurate method of measuring strain. But care should be taken for the temperature changes. In order to enhance the output voltage and cancel away the resistance changes due to the change in temperature, two strain gauges are used to measured the

force at the end of the Cantilever beam.

(2) Piezoelectric sensor. A piezoelectric material exhibits a phenomenon known as the piezoelectric effect. This effect states that when asymmetrical, elastic crystals are deformed by a force, an electrical potential will be developed within the distorted crystal lattice. This effect is reversible. That is, if a potential is applied between the surfaces of the crystal, it will change its physical dimensions. The magnitude and polarity of the induced charges are proportional to the magnitude and direction of the applied force. The piezoelectric materials are quartz, tourmaline, Rochalle salt, and others. The range of forces that can be measured using piezoelectric sensors are from 1 to 20kN and at a ratio of 2×10^5. These sensors can be used to measure an instantaneous change in force (dynamic forces).

(3) Current-based sensing. Since the torque provided by an electric motor is a function of the current drawn, its measurement, along with the known motor characteristics, gives the torque sensing.

11.3.2 External Sensors

External sensors are primarily used to learn more about the robot's environment, especially the objects being manipulated. External sensors can be divided into the contact type and non-contact type.

1. Contact Type

Limit switch. A limit switch is constructed much as the ordinary light switch used at homes and offices. It has the same on/off characteristics. The limit switch usually has a pressure sensitive mechanical arm. When an object applies pressure on the mechanical arm, the switch is energised. An object might have an attached magnet that causes a contact to rise and close when the object passes over the arm. A normally open switch has continuity when pressure is applied. A single pole switch allows one circuit to be opened or closed upon contact, whereas a multi-pole switch allows multiple switch circuits to be open or closed. Limit switches are mechanical devices which have problems that they are subject to mechanical failure, their mean time between failures is low compared to non-contact sensors, and the speed of operation is relatively slow compared to the speed of switching of photoelectric micro-sensors which is up to 3,000 times faster.

Limit switches are used in robots to detect the extreme positions of the motions, where the link reaching an extreme position switch off the corresponding actuator, thus safeguarding any possible damage to the mechanical structure of the robot arm.

2. Non-contact Type

Proximity sensor. Proximity sensing is the technique of detecting the presence or absence of object with an electronic non-contact sensor. Proximity sensors are of two types; inductive and capacitive. Inductive proximity sensors are used in the place of limit switches for non-contact sensing of metallic objects. Capacitive proximity sensors are used on the same basis as inductive proximity sensors. However these can also detect non-metallic objects.

1) Inductive proximity sensor. All of the inductive proximity sensors consist of four basic ele-

ments, namely, sensor coil and ferrite core, detector circuit, oscillator circuit, and solid state output circuit.

The oscillator circuit generates a ratio frequency electromagnetic field. The field is centered around the axis of the ferrite core, which shapes the field and directs it at the sensor face. When a metal target approaches the face and enters the field, eddy currents are induced into the surface of the target. This results in a loading or damping effect that causes a reduction in the amplitude of the oscillator signal. The detector circuit detects the change in the oscillator amplitude and will switch on at specific operating amplitude. This signal turns on the solid state output circuit. This is often referred to as the damped condition. As the target leaves the sensing field, the oscillator responds with an increase in amplitude. As the amplitude increases above a specific value, it is detected by the detector circuit, which is switched off causing the output signal to return to the normal or off state. The sensing range of an inductive proximity sensor refers to the distance between the sensor face and the target. It also indicates the coil and the core. Usual range is up to 10 ~ 15mm but some sensors also have ranges as high as 100mm.

2) Capacitive proximity sensor. A capacitive proximity sensor operates much like an inductive proximity sensor. However, the means of sensing is considerably different. Capacitive sensing is based on dielectric capacitance. Capacitance is the property of insulators to store a charge. A capacitor consists of two plates separated by an insulator, usually called a dielectric. When the switch is closed a charge is stored on the two plates. The distance between the plates determines the ability of the capacitor to store the charge and to determine discrete ON and OFF switching status. One capacitive plate is part of the switch, the sensor face is the insulator, and the target is the other plate. Ground is the common path. The capacitive switch has the same four elements as the inductive sensor, i. e. sensor (the dielectric media), oscillator circuit, detector circuit, and solid-state output circuit.

The oscillator circuit in a capacitive switch operates like the one in an inductive switch. The oscillator circuit includes capacitance from the external target plate and the internal plate. In a capacitive sensor, the oscillator starts oscillating when a sufficient feed-back capacitance is detected. Major characteristics of the capacitive proximity sensors are the following:

① They can detect non-metallic targets;

② They can detect light weight or small objects that cannot be detected by mechanical limit switches;

③ They provide a high switching rate for rapid response in object counting applications;

④ They can detect limit targets through non-metallic barriers (glass, plastics, etc.);

⑤ They have a long operational life with virtually an unlimited number of operating cycles;

⑥ The solid state output provides a bounce-free contact signal.

Capacitive proximity sensors have two major limitations. The sensors are affected by moisture and humidity, and they must have extended range for effective sensing. Capacitive proximity sensors have a greater sensing range than the inductive proximity sensors. Sensing distance for capacitive switches is a matter of plate area, as coil size is for inductive proximity sensors. Capacitive sensors

basically measure a dielectric gap. Accordingly, it is desirable to be able to compensate for the target and application conditions with a sensitivity adjustment potentiometer.

3) Semiconductor displacement sensor. Semiconductor displacement sensor uses a semi-conductor light emitting diode (LED) or laser as a light source, and a position-sensitive detector (PSD). The laser beam is focused on the target by means of a lens. The target reflects the beam, which is then focused on to the PSD forming a beam spot. The beam spot moves on the PSD as the target moves. The displacement of the workpiece can then be determined by detecting the movement of the beam spot.

11.3.3 Vision System

Vision sensors can be classified as external non-contact type. However, they are treated here in a separate section due to their complexity, which requires a detailed treatment. Vision systems are successfully used with robots to let them look around and find the parts for picking and placing them at appropriate locations. Earlier fixtures were used with robots for the accurate positioning of the objects, which are very expensive. Other tasks of vision systems used with robots include determination of the configuration of the objects, motion of the objects, reconstruction of 3D geometry of the objects from their 2D images for measurements, and building up of the maps of the environment for the robot's navigation. Vision systems provide information that is difficult, or impossible, to obtain in other ways. Their coverage is from few millimeters to tens of meters with either narrow or wide angle, depending upon the system needs and design.

1. Elements in Vision Sensor

In a vision system, the principal imaging component is a complete camera including a sensing array, associated electronics, output signal format, and lens. Depending on the application, the camera could be RS-170/CCIR, NTSC/PAL (These are American RS-170 mono colour, NTSC colour, PAL colour television standard signal produced by the video cameras, respectively) progressive scan, variable scan, or line scan. Five major system parameters which govern the choice of the camera are field of view, resolution, working distance, depth of field, and image data acquisition rate. As a thumb rule, for size measurements, the sensor should have a number of pixels that is at least twice the ratio of the largest to the smallest object sizes of interest. Lighting should be arranged to illuminate the objects of interest. A frame grabber or video capture card, usually in the form of a plug-in board which is installed in the computer, is often required to interface the camera to a host computer. The frame grabber will store the image data from the camera in an on-board, or system memory, sampling and digitizing the analog data as necessary. In some cases the camera may output the digital data, which is compatible with a standard computer. So a separate frame grabber may not be needed. Vision software is needed to create the program which processes the image data. When an image has been analysed the system must be able to communicate the result to control the process or to pass information to a database. This requires a digital input/output interface. The human eye and brain can identify objects and interpret scenes under a wide variety of conditions. Machine vision systems are far less versatile so the creation of a successful system requires careful consideration of all

the elements of the system and a precise identification of the goals to be accomplished, which should be kept as simple as possible.

2. Steps in Vision Sensing

The vision sensing, also referred to as machine vision, has two steps, namely, image acquisition and image processing.

(1) Image acquisition. In image acquisition, an image is obtained and digitised for further processing. Although image acquisition is primary a hardware function, software can be used to control light intensity, lens opening focus, camera angle, synchronisation, field of view, read times, and other functions. Image acquisition has four principle elements, namely,

1) A light source, either controlled or ambient;

2) Lens that focuses reflected light from the object on to the image sensor;

3) An image sensor, which converts the light image into a stored electrical image

4) Electronics to read the image from the image sensing element, and after processing transmit the image information to a computer for further processing.

The computer then handles the rest of the steps, i. e. image analysis and pattern recognition.

(2) Image processing. Image processing examines the digitised data to locate and recognise an object within the image field. Different approaches can be used. Most image analysis techniques include segmentation, parameter extraction, and pattern recognition. Segmentation breaks the scene into several pieces or segments and allows the desired object to be isolated; if multiple objects of interest are present, segmentation separates them in the image. Parameter extraction then looks at segmented objects and determines the key feature such as size, position, orientation, shape, intensity, colour and texture. Pattern recognition attempts to match the observed features against stored criterion, thus allowing the objects to be identified. Based on a specific activity during the image processing stage, a vision system is classified as low, intermediate or high level vision.

3. Difficulties in Vision and Remedies

A vision system cannot uniquely represent or process all the available data because of computational problem like memory, and processing time requirements imposed on the computer. Therefore, the system must compromise. Other problems include the variations of light, part-size, part placement, and limitations in the dynamic range available in the typical vision sensors. Vision system requires specialised hardware and software. It is possible to purchase just the hardware with little or no vision application programming. In fact a few third party programs are available. A hardware-only approach is less expensive and can be more flexible for handing the usual vision requirements. But, since this approach requires image processing expertise, it is only of interest to user who wishes to retain the responsibility of image interpretation. It is a usual practice to obtain the hardware and application software together from the supplier. However, the user might still need to do custom programming for an application. Major vision system suppliers specialise in providing software for only a few application areas.

Every vision system requires a sensor in order to convert the visual image into an electronic signal. Several types of video sensors are used, including vidicon cameras, vacuum tube devices, and

solid-state sensors. Many of these vision systems were originally designed for some other application, such as television, so the signal must be processed to extract the visual image and remove synchronisation information before the signal is sent to the computer for further processing. The computer then treats this digital signal as the array pixels, and processes this data to extract the desired information. Image processing can be very time consuming. For a typical sensor of 200,000 or more pixels, a vision system can take many seconds, even minutes, to analyse the complete scene and determine the action to be taken. The number of bits to be processed is quite large, for example, a system with 512×512 pixels array and 8-bit intensity per pixel yields over two million bits to be processed. If a continuous image at a 30-Hz frame rate were being received, data bytes would be received at 8-MHz rate. Few computers can accept inputs at these data rates and, in any case, there would be no time left to process the data. When a higher resolution system, colour system, or the multiple camera systems are considered, data handing requirements become astronomical.

Several methods can be used to reduce the amount of data and therefore, the processing time. They are explained as follows:

1) One approach is the binary vision, which is used when only a black-and-white information is processed (intensity variation and shades of grey are ignored). In binary vision a picture is converted into a binary image by thresholding. In thresholding, a brightness level is selected. All the data with intensities equal to or higher than this value are considered to be white, all other levels are considered as being black.

2) Another method of shortening the process time is to control the object placement so that objects of interest cannot overlap in the image. Complicated algorithms to separate images are then unnecessary, and the image processing time is reduced.

3) A third approach reduces data handing by processing only a small window of the actual data; that is, the object is located in a predefined field of view. For example, if the robot is looking for a mark on the printed circuit board, the television system can be held in such a way that the mark is always in the upper right corner.

4) A forth approach takes a statistical sample of data and makes decisions on this data sample.

Unfortunately, all of these approaches ignore some of the available data and, in effect, produce a less robust system. Processing time is saved, but some types of complex objects cannot be recognised.

11.3.4 Sensor Selection

In using sensors, one must first decide what the sensor is supposed to do and what result one expects. This section discusses some of the characteristics that must be considered in selecting and using different kinds of sensors for robot applications.

1. Range

Range is a measure of the difference between the minimum and maximum values measured. For example, a strain gauge might be able to measure values over the range from 0.1 to 10N.

2. Sensitivity

Sensitivity is defined as the ratio of the change output to a change in input. As an example, if a movement of 0. 025mm causes an output voltage by 0. 02 volts then the sensitivity is 0. 8 volts per mm. It is sometimes used to indicate the smallest change in the input that will be observable as a change in output. Usually the maximum sensitivity that provides a linear, accurate signal is desired.

3. Linearity

Perfect linearity would allow output versus input to be plotted as a straight line on a graph paper. Linearity is a measure of the constancy of the ratio of output to input.

4. Response Time

Response time is the time required for a change in input to be observable as a stable change in output. In some sensors, the output oscillates for a short time before it settles down to a stable value. One measures the response time from the start of an input change to the time when the output has settled to a specified range.

5. Accuracy

Accuracy is a measure of the difference between the measured and actual values. An accuracy of ±0. 025mm means, that under all the circumstances considered, the measured value will be within 0. 025mm of the actual value. In positioning a robot and its end-effector verification of this level of accuracy would require careful measurement of the position of the end-effector with respect to the base reference location with an overall accuracy of 0. 025mm under all conditions of temperature, acceleration, velocity, and loading. [11] Precision measuring equipment, carefully calibrated against secondary standards, would be necessary to verify this accuracy.

6. Repeatability

Repeatability is a measure of the difference in value between two successive measurements under the same conditions, and is a far less stringent criterion than accuracy. As long as the forces, temperature, and other parameters have not changed, one would expect the successive values to be the same, however poor the accuracy is.

7. Resolution

Resolution is a measure of the number of measurements within a range from minimum to maximum. It is also used to indicate the value of the smallest increment of value that is observable.

8. Type of Output

Output can be in the form of a mechanical movement, an electrical current or voltage, a pressure, or a liquid level, a light intensity, or another form. To be useful, it must be converted into another form, as in the LVTD (Linear Variable Differential Transducer) or strain gauges, which were discussed earlier.

In addition to the above characteristics, the sensors should have suitable physical characteristics. For example:

(1) Size and weight. Size and weight are usually important physical characteristics of sensors. If the sensor is to be mounted on the robot hand or arm, it becomes a part of the mass that must be accelerated and decelerated by the drive motors of the wrist and arm. So, it directly affects the

performance of the robot. It is a challenge to sensor designers to reduce the size and weight. An early wrist force-torque sensor, for example was about 125mm in diameter but was reduced to about 75mm in diameter through a careful redesign.

(2) Reliability. Reliability is of major importance in all robot applications. It can be measured in terms of Mean Time to Failure (MTTF) as being the average number of hours between the failure that causes some part of the sensor to become inoperative. In industrial use, the total robot system is expected to be available for as much as 98% or 99% of the working days. Since there are hundreds of components in a robot system, each one must have a very high reliability. Some of the otherwise good sensors cannot stand the daily environmental stress and therefore cannot be used with robots. Part of the requirement for reliability is the case of maintenance. A sensor that can be easily replaced does not have to be as reliable as the one that is hidden in the depths of the robot. Maintainability is hence a measure in terms of Mean Time to Repair (MTTR).

(3) Interfacing. Interfacing of sensors with signal conditioning devices and the controller of the robot is often a determining factor in the usefulness of sensors. Non-standard plugs or requirements for non-standard voltages and currents may make a sensor too complex and expensive to use. Also, the signals from a sensor must be compatible with the other equipment being used if the system is to work properly.

(From *Introduction to Robotics* by S. K. Saha)

难句释义

① 翻译时将“these robots”提到句首。全句译为：这些机器人效率很高但是完全没有情感，因此起初被认为是人类的改进，因为它们会没有任何质疑地服从人类的指示。

② a multitude of 意为“大量的”。全句译为：从那时起，机器人在许多领域得到了长足的发展，在焊接、喷涂、装配、机床装载和卸载、检查、农业、医护、医疗、军队、安全和机床行业广泛应用，并应用于海底和空间探索。

③ 该句给出机器人的两种并列的定义，一种是“manipulator”，另一种是“specialized devices”。全句译为：国际标准组织（ISO）将机器人正式定义为：机器人是用以搬运材料、零件、工具的可编程序的多功能操作器，或是通过可改变程序动作来执行各种作业的特殊机械装置。

④“retained”和“reprogrammed”为近义词，只翻译一个即可；an array of 意为“大量，一系列”；whereas 意为“然而”。全句译为：但是，机器人很容易通过重新编程来执行一系列不同的作业，然而自动化专用机床，包括计算机数控机床，只能执行有限种类的任务。

⑤ automotive sector 意为“汽车行业”。全句译为：但是近来，除了汽车行业外，来自电子元件产业、通信设备产业和计算机产业对机器人的强烈需求也加强了机器人的市场占有率。

⑥ exceptionally 意为“格外地，异常地”；capacity 意为“生产能力”；reach 意为“行程”。全句译为：工业机器人是非常强大的设备，尤其是那些生产能力大、行程大的设备。

⑦ to this end 意为“为此”；in-built 意为“内置的”。全句译为：为此，机器人内置有双重安全链条或运行链条。

⑧ i. e. 意为“也就是”；etc. 意为“等等”。全句译为：对于焊缝焊接，一些供应商可提供由机器人构成的完整的焊接系统，也就是将焊接设备与其他材料处理装置，如转盘等，集成为一个单元。

⑨ 全句译为：霍尔芯片是一种平板导体材料。若在霍尔芯片的两个对面连接一个电位差，则通过与其垂直平面的电压为0。

⑩ spring balance 意为“弹簧秤”。全句译为：弹簧秤就是力传感器的一个例子。弹簧秤工作时，一种力即重量作用于秤盘引起位移，即弹簧的拉伸。

⑪ positioning 为动名词结构，意为“定位”；句子主干为“verification of this level of accuracy would require careful measurement of the position of the end-effector”；base reference location 意为“基准参考部位”。全句拆译为两句，译为：在定位机器人及其末端执行器时，需精确测量出末端执行器相对于基准参考部位的位置。只有该测量值在所有的温度、加速度、速度及加载情况下均能达到0.025mm的精度时，才能验证精度满足0.025mm的要求。

Oral Practices and Team Working

Part 3 口语训练和团队合作

本部分为本书设置的第二个专业英语实践环节——口语训练和团队合作，介绍了英语面试常用表达、英文学术报告设计方法以及国际学术会议交流用语，辅助情景教学。

本部分的学习侧重培养英语沟通能力和协作精神。学习时可以参考书中介绍的英语面试常用表达、英文学术报告设计方法以及国际学术会议交流用语，鼓励学生设计与专业领域相关的情景主题、自主发挥完成情景细节与表演，提升口语表达、听力水平及培养团队合作精神。

英语面试常用表达

求职或求学深造的第一道门槛就是面试，而英语面试是所有外企、大多数国内知名企业面试，国外高校留学面试，国内高校研究生复试的必设环节。对于母语不是英语的应聘者或求学者，平时进行英语日常对话的机会很少，且基本上都是采用中文的思维方式，在进行英语口语面试过程中不能本能地反映出提问的内容，必须在脑中逐字翻译好，才能完全领会。因此，如果没有在英语面试之前进行充分的准备，对于面试官的英语提问往往会感到不知所措，再加上面试官语速较快，或者紧张情绪等外在影响，很容易搞砸面试。

想要改善英文面试中的表现，需要求职者增加英语口语的日常训练，培养英语口语沟通能力，这样在面试遇到突发情况时，也能应对自如。除此之外，应对英语面试的最重要的方法就是在面试前做好充分的准备，包括了解英语面试过程及注意要点，准备完善的自我介绍，了解常见问题及应答，以及掌握面试常用语句，这些环节都离不开自身的专业背景，因此都涉及专业英语的运用。

12.1 英语面试过程及注意要点

12.1.1 典型英语面试过程简介

1. 外企面试

外企英语面试一般包括三轮：第一轮面试一般由公司人力资源部的人员担任考官，他们会从你的个人简历出发，询问一些有关个人的问题，比如请你用英语做一个自我介绍。第一轮面试可能是电话面试，也可能是英语笔试，考查应聘者基本的语言运用能力。

第二轮面试则由部门主管经理出面，这时候有关业务方面的问题成了面试的重点，所以英语面试也从个人情况转向了专业领域。比如应聘工程部，面试官可能要求应聘者介绍自己的专业背景、工程经验、设计经历等。在这一轮面试中，应聘者必须具备较高的专业英语应用能力，熟悉专业表达和词汇，给面试官留下专业、干练的印象。

如果前面都很顺利，那么最后一轮的面试官一般就是公司的总裁了。外企的总裁一般是老外，因此该轮面试往往是全英语的了。总裁询问的问题一般会和公司的精神、企业文化有关。外国人作为考官进行面试时，由于他们与我们的思维方式、习惯以及文化有所差别，因此必须熟悉他们的思维方式和语言表达方式，这就需要在日常生活中训练。

2. 留学面试

在申请美国大学过程中，面试是一个非常重要的环节。在这个环节中，面试官会非常直

接且清晰地了解到学生的能力，从而进一步确认此人是否是学校需要的人才。虽然面试对于申请结果的获得并不会起到决定性的影响，但是如果准备得不好或者口头表达能力太差，往往会导致申请功亏一篑。

一般面试的时间大概要 20 ~ 30 分钟，有长些的可能会达到 40 分钟。开始时面试官会先进行自我介绍，并核对考生的个人信息或要求考生做一个简短的自我介绍，接下来会就考生的专业背景、研究经历展开话题，然后面试官可能会介绍自己的科研课题或者实验室。一般在谈话结束的时候，面试官会留出时间让考生问些问题，此时考生可以抓住机会多了解学校和申请专业的情况。

从形式上看，留学面试主要分为三种：现场面试、视频面试和电话面试。在现场面试中，学生跟招生人员有更多的互动机会，学生应该学会随机应变，根据现场情况迅速给予反应。面试时眼睛要直视对方，目光游移不定会影响面试官对你的信赖。视频面试是近几年来比较热的一种留学申请评估方式。在视频面试中，要注意自己的整体形象，尽量穿正装，多微笑，恰当使用肢体语言，既可以缓和尴尬的气氛，又不至于太过生硬。在电话面试中，要求被面试者口齿要清晰，尽量让自己的说话处于最佳状态。电话面试对学生的表达能力要求更高，但由于“只闻其声不见其人”的特点，电话面试时，可在手边记录，也可放一些参考资料，作为回答的参考，但不能直接照读。

3. 研究生复试英语面试

研究生阶段的深造需要学生进行系统的课题研究，发表较高水平的科研成果。课题研究从文献综述开始，到最后的科技论文和学位论文写作，都离不开专业英语的应用。因此研究生复试中一般都设置英语面试环节，用来考查学生的英语听、说、阅读、翻译能力及专业英语的掌握水平。英语复试的内容因学校、专业的不同而异，但形式上大概有以下三种：

（1）自我介绍　在面试开始时，常常会给考生几分钟的时间进行自我介绍。内容包括基本信息、专业背景、学习和科研经历、爱好和特长等，主要考核考生的英语口语基本水平。

（2）问答环节　问题可能是日常生活方面的，也可能是专业知识相关领域的，考核考生的基本英语听说能力，了解考生的专业知识掌握情况及专业英语的运用能力。

（3）能力考核　能力考核的形式有很多种，可能给考生一篇专业领域的英语短文，要求考生在规定的时间内看完、理解并做翻译，并回答考官提出的针对性的问题，主要考核考生的阅读、翻译和口语表达能力；可能给考生一个或一系列图片，在规定时间内写一篇英语短文，主要考查考生的基本写作能力；也可能设计一个话题，给几分钟的思考时间，要求两个或以上考生进行对话或辩论，主要考查口语表达能力、思维能力和是否具有团队精神等。

12.1.2　英语面试注意要点

成功的英语面试可以帮助求职者或求学者充分地展示自己，提升被录取的概率；相反，失败的英语面试可能会导致自己的努力功亏一篑，错失良机。成功的英语面试离不开应试者平常的努力和训练，但也需要应试者在面试前做好充分的准备，在面试时表现优秀。

1. 充分准备

（1）做好自我准备　准备好自己的个人情况及专业背景或业务方面的介绍，对自己的情况烂熟于胸，对自己的所有应聘资料——学历、简历、各种证书、证明资料、推荐人、证

明人的姓名、地址等都能倒背如流，整理出资历、背景资料、个性或兴趣中最能显示出发展潜能、最能引起主试者注意及与所应聘的工作有最直接关系的内容，以便能从容应付主试者的提问。尤其要对专业英语准备充足，因为经常会被要求用英语解释一个专业术语或回答一个技术问题。

（2）多方面了解应聘企业或申请的学校，以及申请岗位或专业　通过报纸、图书馆、在该公司工作的熟人、网站等途径或其他渠道了解一下企业的情况，包括名称、主要产品或经营范围、过去的业绩和未来的发展方向、文化特征（经营理念、企业精神、形象识别等）、总部或总公司所在地、经营者姓名、社会贡献、广告等，并找一找自己的专业背景或工作经历与该企业的联系，做一下在该企业中的职业规划；了解学校的办学特色、找出与自己专业背景或兴趣爱好相符的方面，准备回答面试官“为什么选择我们学校”的问题。这点很重要，无论哪所学校都非常希望招到适合自己学校的学生，反之，无论哪个学生也都非常希望申请到适合自己的学校。

（3）了解面试官的基本情况　可能的话，通过网络搜索或熟人了解等方式对面试官做必要的了解，包括其教育和工作背景，以及其个人爱好和兴趣等，有助于理解面试官的提问内容及目的。

（4）反复模拟演习　在参加实际面试前，应聘者可自己根据所掌握到的资料自行提问，自行回答，来一番“实战”前的演习。这对于确保面试成功是十分重要的，尤其是对初出校门的青年学生而言更是如此。反复演习可以使应聘者逐渐熟悉所有资料，更好地理解面试官的提问，对一些面试中必定会被问到的问题更加胸有成竹，避免在现场听不懂提问、表述不清、词不达意。

2. 仪表庄重、彬彬有礼

穿着正式、整洁，不能过于休闲或随便，要体现出对面试机会的重视和对面试官的尊重。男生应该尽量穿西服、衬衫，女生应该打扮得体，不要穿紧身衣或短裙。面带微笑，笔直站立，不要有过多的小动作，更不要嚼口香糖或抽烟，力求给人稳重踏实的印象。

细节往往决定成败，礼貌在整个面试过程中尤为重要。入座礼仪：进门的时候一定要敲门；礼貌地表示对面试官的尊重，可以鞠躬或者问好；须等主试者示意后，在指定位置与面试官面对面就座，将随身携带物品放于旁边（进门前关闭手机）。自我介绍时严格控制时间，不要耽误面试官或其他面试者的时间。回答问题时要礼貌，如当你感觉所问问题有人身攻击、谴责等含义且又与工作无关时，可以婉转地回答“I am sorry, I don't think this question have anything to do with the job”，而避免回答“Why do you ask such a rude question?”，造成场面尴尬。面试结束后，离开时致谢面试官，并将椅子放好。

3. 心态自信、态度诚恳

面试中的英语部分以考查应用能力为主，所以应聘者在面试当中最需要的是自信。自信表现之一是放松自然、不紧张，与面试官有适当的眼神交流，不要低着头或东张西望；自信表现之二是敢说，回答问题时能够用简洁、流畅的英语表达，灵活应变。如果你表现的足够自信，面试官会觉得你更能胜任工作，因此被录取的概率更大。

面试的时候一定要诚实，不会的时候就诚实地说自己不是很了解，把自己所了解的客观地说出来，不要遮遮掩掩，企图蒙混过关。另外，对于面试官的问题没听懂或没听清时，也要大胆说出来，请对方再重复一遍，不要想半天什么也不说更不要信口开河，影响自己的诚

信度。

4. 谈吐清晰、举止得当

面试的主要形式就是谈话，甚至主要是应聘者一方说话，而主试者则借此对应聘者做全方位的了解。因此，面试中应聘者的谈吐极为重要，要求表达流利、思维连贯、吐字清楚、音量适当、语速平稳，不要夹杂中文，可以用“well”“however”这样的过渡词来给自己停顿和思考，同时，也使得自己的表述显得口语化一些。自我介绍要简洁、层次清楚、重点突出，避免长篇大论。回答问题、发表意见必须注意分寸，留有余地。

就姿势而言，应保持“站如松，坐如钟”的姿势，避免频繁的身体晃动，表现出精力充沛、充满自信，有比较强的自制力，给主试者留下好印象。此外，进入面试考场，如果发现各方位置都已经确定好了，那就按照位置就座；如果并没有指定确切的座位，应该与主试者保持一般社交围内的范距离，不能太近或太远。

12.2 英语自我介绍

12.2.1 内容和要求

自我介绍是大部分英语面试中的第一关，是面试官考查应试者英语水平、语言表达能力等方面的重要环节，直接会关系到应试者给面试官的第一印象，以及是否能得到进阶下一轮面试的机会，因此每个求职者或求学者都应该精心准备自我介绍，尤其对于英语面试，更需要花时间去准备来克服语言上的困难。

从内容上讲，自我介绍应大体包括个人信息（包括姓名、单位或毕业院校、职务或学历等）、教育背景、专业背景、工作或研究经历、专业技能、能力和业绩、特长及爱好等。介绍的内容不宜太多地停留在诸如姓名、工作经历、时间等东西上，因为这些内容在简历表上已经明确了，而应该重点阐述与所应聘职位有关的以下内容：

（1）专业技能　是否具备工作所需的专业技能是考查应聘者是否适合这项工作的重要依据，因此应该在自我介绍中阐述，打消面试官对该方面的疑虑。对于应届生来说，专业技能主要体现在自己的专业、学历背景上，因为所学的东西正是企业所需要的。

（2）突出能力和工作业绩　证明自己某方面突出的能力或工作业绩时最好能用事实和数字说话，这种形式更有说服力。比如在说明创新、动手能力较强时，可以用创新大赛获奖、参加实践活动、发表研究论文之类的论据证明，但是论据要真实可靠，不可造假。

（3）工作经验　用人单位特别重视应聘者是否做过空缺职位的相关工作，并积累了相关经验，能否以最快的速度投入到工作中去，并带来新的思路和方法。申请留学时，前阶段在读期间除了学习之外的工作、实践、科研经验也很重要，是学生全方位综合素质的体现。

在准备自我介绍时，还需注意以下要求：

1）在自我介绍之前应礼貌地做一个极简短的开场白。

2）分别准备一个长的和一个短的自我介绍，以应变面试现场不同的要求。

3）内容的逻辑性要强，避免说一些与职业无关的事。

4）避免语法错误，尤其注意英语时态的变化运用。

5）不要为了给面试官留下英语水平高的印象，频繁使用花哨的词汇及句式，而应该以

英语为载体展示工作才能。

6）概括说出工作经历和学历，切勿背诵。

7）推销自己的长处，如非必要，尽量不要提及自己的弱点。

8）可以的话，尽量说得幽默有趣，营造活泼和睦的气氛。

9）尊重个人及文化差异。

10）注意控制时间，既不能超时太长，也不能过于简短。

12.2.2 范例解析

自我介绍范例（一）：求学面试

开场白：

Good morning, my name is ×××. It is really a great honor to have this opportunity for an interview. I hope I can make a good performance today, eventually enroll in this prestigious university in September.

个人信息：

Now I will introduce myself briefly. I am ×× years old, born in ××× Province, and currently I am a senior student at ××× University. My major is Mechanical Engineering, and I will receive my Master Degree after my graduation in June.

教育背景：

In ×××, I entered the ××× University. During the following undergraduate study, my academic records kept distinguished among the whole department. I was granted First Class Prize every semester. In ×××, I got the privilege to enter the graduate program waived of the admission test.

学习成绩（阐述重点一）：

At the period of my graduate study, my overall Grade point (×××) ranked top ×% in the department. In the second semester, I became teacher assistant that is given to talented and matured students only. This year, I won the National Scholarship as the one of candidates in my university, which is the ultimate accolade for distinguished graduate students. Presently, I am preparing my graduation thesis and trying for the honor of Excellent Graduation Thesis.

研究经历和学术活动（阐述重点二）：

During the graduate research, I followed the guide of my supervisor, learning the major methods of conducting scientific research well. I have learned how to design a prototype, how to test its performance by the theoretical, simulating and experimental means, how to present myself and research work, and how to communicate with others and work independently. Around my research work, I have published ××× academic papers and applied for ×× patents of my original design. Meanwhile, I also attended several academic conference in the related area, expending my scientific horizons and simulating my creative ideas.

兴趣爱好：

In my spare time, I like to read books, listen to classic music, watch movies and play volleyball. They keep me in good health, full of energy and open-minded.

结束语：

In retrospect, I find myself standing on a solid basis in both theory and experience, which has prepared me for the Ph. D. program. My future research interests include: ×××. That's all. Thank you for your attention.

自我介绍范例（二）：求职面试

开场白：

Good morning, ladies and gentlemen! It is really my honor to have this opportunity for an interview. I hope I can make a good performance today. I'm confident that I can succeed.

个人信息：

Now I will introduce myself briefly. I am ××× years old, born in ××× Province. I graduated from ××× University and my major is Mechanical Engineering. I got my Bachelor Degree after my graduation in the year of ××××. During university time, I spent most of my time on study, have acquired basic knowledge of my major, and passed CET-6 with excellent record.

工作经验：

In July ×××, I began to work for a foreign enterprise ××× as a mechanical engineer. To change my working environment and pursue more challenge, I'd like to find a job in ×××, a global company which could offer me larger lifting space. That is the reason why I come here to compete for this position. I think I am a highly-motivated and reliable person with excellent health and pleasant personality. Also I am able to work under great pressure and time limitation. With my professional background and related working experiences, I am confident that I am qualified for the post of engineer in your company.

结束语：

That is all. Thank you for giving me the chance.

12.3 英语面试常用表达

12.3.1 常用对话示例

（I = Interviewer 面试官　A = Applicant 应聘者）

1. 开场白

A: Excuse me. May I see Mr. John Watt, the Manager?

I: It's me. What can I do for you?

A: I have come at your invitation for an interview. Nice to meet you, Mr. Watt.

I: Nice to meet you too. Please sit down.

A: Thank you, sir.

I: We have received your letter in answer to our advertisement. I would like to talk with you regarding your qualifications for this position.

A: I am very happy that I am qualified for interview. Thank you.

2. 教育背景

I: Would you tell me what educational background you have?

A: Yes, sir. I graduated from middle school in 2013, then I entered ××× University and graduated in 2017 with a Bachelor Degree.

I: What's your major in university?

A: Mechanical Manufacturing and Automation.

I: What course did you like best?

A: I was very interested in Robotics. I think in the future, robots will become common in our daily life.

I: How were your grades at college?

A: They were all above average.

I: How do you think the education you've received will contribute to your work in this institution?

A: I have already learned a lot in the classroom and I hope to be able to make practical use of it in business in your company.

I: Were you in a leading position when you were a college student?

A: Yes, I was president of student union of our university, and I joined the Communist Party of China in my junior year.

I: Did you get any honors or rewards at your university?

A: Yes. I was elected an excellent league member for three academic years on end.

3. 工作经验

I: Have you had any experience with computers?

A: Yes, I studied in a computer training program, and can process data through the computer.

I: Where are you working?

A: I work at ×××.

I: How long have you been working there?

A: I have been working there since I left my previous employer in 2015.

I: How many employers have you worked for?

A: Three.

I: What work were you responsible for at your previous work unit?

A: I was responsible for prototype design.

4. 工作成就

I: Now please tell me something about your achievements in your work unit.

A: All right, madam. When I was the mechanical engineer of ×××, I succeeded in design a new version of product, increasing the production rate of 20%.

I: Have you receive any honors?

A: Yes. I was chosen as one of "The Big Ten Prominent Youths" of Hainan in 2015.

5. 辞职原因

I: Why do you plan to change your job?

A: I would like to have a job that is livelier than my present one with more lifting space.

I: Why have you changed your job so frequently?

A: My first job was in a well established company where the division of labour is very clear. I do not have much change to enrich my experience. Then I got an opportunity to really broaden my experience with a new company that was starting up, but unfortunately, they closed three months' time. I have worked in my present company for a considerable length of time and enjoy the job I am doing now. However, I think I have accumulated enough experience to take up more challenging post in a much larger and diversified company where I could make solid contribution.

6. 应聘原因

I: What made you choose this company?

A: Your company has earned a very good reputation, not only because your products are of high quality, but also your well-constructed management system. I want to contribute my effort to such an outstanding company which cares not only the customer' needs, but also welfare of the employees.

I: Why do you consider yourself qualified for the job?

A: I have the educational background and relevant experience required by the job. Besides, I am a very good team player and have the desire to make a thorough success.

I: What would you like to be doing five years from now?

A: I hope I could be a leader of an energetic and productive R&D team.

7. 个人能力

I: What is your greatest strength?

A: I think I am very good at planning. I manage my time perfectly so that I can always get things done on time.

I: What are your weak points?

A: When I think something is right, I will stick to that. Sometimes it sounds a little stubborn but I am now trying to find a balance between insistence and compromise.

I: What are your greatest accomplishments?

A: Although I feel my greatest accomplishments are still ahead of me, I am proud of my involvement with the International Manufacturing Conference'97 project. I made my contribution as part of that team and learned a lot in the process.

I: Can you work under pressure?

A: Yes, I find it stimulating. However, I believe planning and proper management of my time reduce deadline panic.

I: Are you more of a follower or a leader?

A: I don't agree with someone else if I think his opinion is wrong, but when I understand his thinking and see he has some good ideas, I'm very happy to go along with him.

8. 个人技能

I: What certificates of technical qualifications have you obtained?

A: I've received a Business English Certificate/Computer Operator's Qualification Certificate.

9. 个性、性格

I: What kind of personality do you think you have?

A: I am quite active and energetic. I approach things enthusiastically and I don't like leaving things half done.

I: Do you think you are introverted or extroverted?

A: I am quite outgoing, I think. I enjoy mixing and doing things with others.

I: What kind of people do you like to work with?

A: People who are honest, dedicate to their work and have integrity.

I: What kind of people you find difficult to work with?

A: Slackers and those who violate working procedures and ignoring deadlines.

10. 业余爱好

I: What do you do in your spare time?

A: I have many hobbies. I like almost all kinds of sports and I also like to listen to classical music.

I: What kinds of sports do you like the most?

A: I like playing football the best. Football is a very exciting game because it keeps you alert and I also enjoy the team spirit of football.

I: What kinds of books do you like?

A: I enjoy reading biographies, especially those of well-known statesmen, militarists, scientists and artists. I can learn a lot from their life histories.

11. 薪资问题

I: What's your expected salary?

A: What is important to me is the job and people I will be working with, so regarding salary, I leave it to you and I am sure that you will make me a fair offer.

I: I can offer you 3,000 yuan per month. Raises are given after three months' probation period according to your performance. Is this satisfactory?

A: Yes, it is quite satisfactory. I accept it.

12. 节假日和福利

I: Is there anything you want to ask me?

A: Um... Yes, can you tell me something about holidays and things like that?

I: There are four weeks of holidays a year, excluding the public holidays, and the starting salary for our departmental managers depends on age, experience, and qualifications, and so on.

13. 到任时间

I: What date can you start to work?

A: I won't able to leave the University until I get my diploma and Bachelor's Degree certificate at the end of this month. How about early next month?

I: That'll do. Please come in on August 1st. Working hours are from eight to twelve in the morning and from two to six in the afternoon. We usually work for five days a week, but occasionally we have to work overtime.

A: Yes, sir.

14. 应聘结果

I：Since there are other applicants on the line, we can't let you know our decision yet until all of them have got their chances for interview.

A：Fair enough, I am willing to wait until you have come to a decision.

I：We will let you know probably next Tuesday. I hope to give you the positive reply.

A：Thank you, I will be glad to hear that.

15. 结束面谈

I：All right. Thank you for your coming, Mr. Wang. I hope to see you again.

A：Thank you for your interview with me, sir. Good-bye.

I：Bye.

12.3.2 常用词汇

表 12-1 面试常用词汇示例

(1) 个人信息					
英文	中文	英文	中文	英文	中文
pen name	笔名	alias	别名	street	街
road	路	district	区	house number	门牌
lane	胡同	blood type	血型	address	地址
birthplace	出生地点	birthdate	出生日期	autonomous region	自治区
province	省	city	市	county	县
nationality	民族，国籍	citizenship	国籍	native place	籍贯
postal code	邮政编码	marital status	婚姻状况	family status	家庭状况
married	已婚	single	未婚	divorced	离异
short-sighted	近视	far-sighted	远视	membership	会员，资格
president	会长	vice-president	副会长	director	理事
standing director	常务理事	society	学会	association	协会
secretary-general	秘书长	research society	研究会	ID card	身份证
(2) 个人品质					
英文	中文	英文	中文	英文	中文
able	能干的	adaptable	适应性强的	active	主动的，活跃的
aggressive	有进取心的	ambitious	有雄心壮志的	amiable	和蔼可亲的
amicable	友好的	analytical	善于分析的	apprehensive	有理解力的
audacious	大胆的	aspiring	有志气的	capable	有能力的
careful	仔细的	candid	正直的	competent	能胜任的
constructive	建设性的	cooperative	有合作精神的	creative	富于创造力的
dependable	可靠的	dedicated	有奉献精神的	diplomatic	有策略的

（续）

(2) 个人品质					
英　文	中　文	英　文	中　文	英　文	中　文
disciplined	守纪律的	dutiful	尽职的	well-educated	受过良好教育的
efficient	有效率的	energetic	精力充沛的	expressivity	善于表达
faithful	忠诚的	frank	直率的	generous	宽宏大量的
genteel	有教养的	gentle	有礼貌的	humorous	有幽默感的
impartial	公正的	independent	有主见的	industrious	勤奋的
ingenious	有独创性的	motivated	目的明确的	intelligent	理解力强的
learned	精通……的	logical	条理分明的	methodical	有方法的
modest	谦虚的	objective	客观的	precise	一丝不苟的
punctual	守时的	realistic	实事求是的	responsible	负责的
sensible	明白事理的	sporting	光明正大的	steady	踏实的
systematic	有系统的	purposeful	意志坚强的	sweet-tempered	性情温和的
temperate	稳健的	tireless	孜孜不倦的		

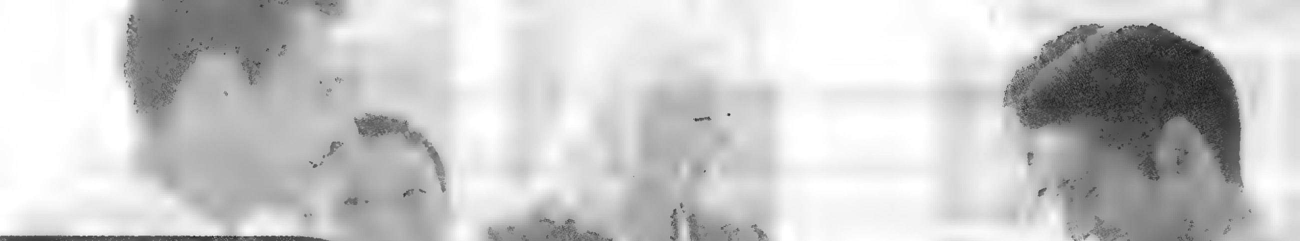
(3) 教育背景					
英　文	中　文	英　文	中　文	英　文	中　文
education	学历	educational background	教育程度	curriculum	课程
major	主修	minor	副修	specialized courses	专门课程
courses taken	所学课程	special training	特别训练	social practice	社会实践
part-time jobs	兼职工作	summer jobs	暑期工作	vacation jobs	假期工作
refresher course	进修课程	extracurricular activities	课外活动	physical activities	体育活动
recreational activities	娱乐活动	academic activities	学术活动	social activities	社会活动
rewards	奖励	scholarship	奖学金	excellent League member	优秀团员
excellent leader	优秀干部	student council	学生会	off-job training	脱产培训
in-job training	在职培训	educational system	学制	academic year	学年
semester	学期（美）	term	学期（英）	supervisor	论文导师
pass	及格	fail	不及格	marks	分数
examination	考试	degree	学位	post doctorate	博士后
doctor（Ph. D）	博士	master	硕士	bachelor	学士
graduate student	研究生	abroad student	留学生	undergraduate	本科生
government -supported student	公费生	commoner	自费生	extern /day-student	走读生
intern	实习生	prize fellow	奖学金生	boarder	寄宿生
graduate	毕业生	guest student	旁听生（英）	auditor	旁听生（美）

（续）

(4) 工作经历					
英　　文	中　　文	英　　文	中　　文	英　　文	中　　文
work experience	工作经历	occupational history	工作经历	professional history	职业经历
specific experience	具体经历	responsibility	职责	second job	第二职业
achievements	工作业绩	administer	管理	assist	辅助
adapted to	适应于	accomplish	完成	appointed	被任命的
adept in	善于	analyze	分析	authorized	授权的
behave	表现	break the record	打破纪录	breakthrough	突破
control	控制	conduct	经营，处理	cost	成本，费用
create	创造	demonstrate	证明，示范	decrease	减少
design	设计	develop	开发，发挥	devise	设计，发明
direct	指导	double	加倍	earn	获得，赚取
effect	效果，作用	eliminate	消除	enlarge	扩大
enrich	使丰富	exploit	开发	enliven	搞活
establish	设立	evaluation	估价，评价	execute	实行，实施
expedite	加快，促进	generate	产生	good at	擅长于
guide	指导，操纵	improve	改进，提高	initiate	创始，开创
innovate	改革，革新	invest	投资	integrate	使一体化
justified	合法化的	launch	开办	maintain	保持，维修
modernize	使现代化	negotiate	谈判	nominated	被提名； 被任命的
overcome	克服	perfect	使完善	perform	执行，履行
profit	利润	be promoted to	被提升为	be proposed as	被提名为
realize	实现	reconstruct	重建	recorded	记载的
refine	精练，精制	registered	已注册的	regenerate	更新，使再生
replace	接替，替换	retrieve	挽回	revenue	收益，收入
scientific	科学的	self-dependence	自力更生	serve	服务，供职
settle	解决	shorten	减少……	simplify	简化，精简
spread	传播，扩大	standard	标准，规格	supervises	监督，管理
supply	供给，满足	systematize	使系统化	test	试验，检验
well-trained	训练有素的	valuable	有价值的	target	目标，指标
working model	劳动模范	advanced worker	先进工作者	objective	目标
(5) 求职应聘					
position desired	希望职位	job objective	工作目标	career objective	职业目标
position sought	谋求职位	position applied for	申请职位	prospects of promotion	晋升的前途
higher responsibility	更高层次的工作	wider experience	扩大工作经验	close-down of company	公司倒闭
expiry of employment	雇用期满	seek a better job	找一份更好的工作		

（续）

（6）兴趣爱好					
hobbies	业余爱好	play the guitar	弹吉他	reading	阅读
play chess	下棋	play	话剧	listening to symphony	听交响乐
sewing	缝纫	jogging	慢跑	long distance running	长跑
play bridge	打桥牌	collecting stamps	集邮	play tennis	打网球
travelling	旅游	do some clay sculptures	搞泥塑		



Unit 13

英文学术报告设计与国际学术会议交流用语

国际学术会议是国内外同行间进行面对面学术交流最普遍和最有效的方式之一。英文学术报告是国际学术会议交流的一种重要且有效的载体，同时也是展现研究成果、探讨学术问题、了解科研前沿动态的最重要手段之一。学习做英文学术报告的过程就是专业英语的深入学习、强化训练和综合实践，有利于拓展专业视野、提高英语表达能力。除了掌握学术报告时的常用口语表达之外，还需要熟悉或掌握会议各种场合、各种角色人物的口语表达，以增进互相理解，提升学术交流效果。

本章内容包括两大部分，即英文学术报告的设计和国际学术会议交流用语。第一部分包括 13.1 ~ 13.5 节，将依次介绍学术报告概述、学术报告的资料搜集与整理、学术报告的结构、报告电子演示文稿设计要求、讲演前准备与临场发挥。第二部分，即 13.6 节，将介绍国际学术会议中与主持人、报告人及互动交流相关的口语表达。

13.1 学术报告概述

13.1.1 学术报告与论文的区别

研究工作结束后，应该把科研成果总结、凝练写成学术论文发表，同时为扩大科研成果的影响力、有效地与同行交流，也应该参加国际或国内的学术会议，通过学术报告的形式进行交流。很多人在初次做学术报告时，由于不了解学术报告和学术论文的区别，认为做学术报告只是简单地将论文原封不动地在会上读一下，所以未获得预期的交流效果。因此，学习做学术报告之前，首先需要了解其与学术论文的区别。

1）学术论文是用文字表达的，学术报告是用语言表达的。这两种表达方式的根本区别就决定了写论文和做报告的不同。

2）看论文的人是主动要看的，听报告的人却不全是主动要听的，所以能否吸引听众，将自己的观点准确地传递给听众，是报告者首先遇到的挑战。

3）看论文是不受时间限制的，因此有看不明白的地方可以反复看，并借助网络、书籍等工具来理解；而听报告是有时间限制的，听众没有时间了解报告的背景知识和听不明白的问题。因此，报告应该深入浅出、重点突出，以防流失听众。

4）看论文时读者看不到作者，因此作者的形象、风度、谈吐、表达等不会影响读者的

阅读兴趣和阅读效果；而听报告时，听众直接面对的是报告人，报告人给听众产生的个人印象会使报告内容额外加分或减分，同时也会影响到报告内容的可信度。

13.1.2 学术报告的类型

在每个大学生的成长和今后步入社会的过程中，都会遇到不同场合下展现自身、成果或产品的机会和挑战，展现的过程就是一个做报告的过程。在各种学术场合下或以学术交流、学术成果展示为目的所做的报告都可以称为学术报告。学术报告是根据专题分组的，因此听众是相同或相近行业或研究领域的学生、学者或者行业专家；学术报告的时间通常控制在30分钟以内，因此汇报内容需要抓重点而不是赘述所有细节。

1）根据学术报告所传达的信息，可以将学术报告分为提供信息型、指导型、激励型、说服型和决策型。

提供信息型报告需要简明扼要地传达要点信息、陈述事实，避免复杂纷乱的信息；指导型报告需要通过设计活动使听众对新知识或新技术印象深刻，并鼓励他们去使用新获得的知识或技术，研究进展报告可采用上述任一形式。激励型报告是让听众对所阐述的问题或现状进行思考，获得听众的积极支持或是理解，如文献阅读报告和综述报告。说服型报告试图让听众接受报告人针对一个问题或争论提出的建议或解决方案，因此报告人必须让听众确信他对这个问题及其所有的解决方案都已彻底检验，最终确定的方案是最优和最可行的，如开题报告和项目可行性论证报告。决策型报告中有一个希望听众采取的建议性行为，而他们可能决定什么都不做，因此报告人必须说服听众采纳自己的建议并告知如何去做，必要时还需强调什么都不做的负面结果，如开题报告、项目可行性论证报告和竞标报告。

2）根据报告人的身份及所处场合，学术报告主要分为学术会议报告、研究项目阶段报告、研究生培养报告、本科生专题报告等。

学术会议报告主要有大会报告、特邀报告和分组报告。大会报告是受会议主办方邀请，本领域权威专家在主会场开幕式结束后，向参会者介绍近期本领域主要研究动向的报告。受邀做大会报告是报告人的荣誉，也是大家对报告人工作和水平的肯定。特邀报告是在分会场或不分组的专题研讨会上，应邀做的学术报告，报告人一般也是某专题领域内学术成就得到认可的专家。分组报告是在专题分会场中，报告人自发的与相近领域专家学者交流自身研究成果所做的报告。

研究项目阶段报告包括项目的竞标、汇报、结题、评估等各阶段的报告。研究生培养报告攻读博士学位或硕士学位期间需要做的学术报告，一般包括开题报告、工作汇报、中期汇报、预答辩和答辩，每个报告侧重的内容不同。本科生的专题报告是本科生根据所学专业知识和自身的专业兴趣点，向老师或同学介绍专业新技术的综述型报告。通过做专题学术报告，可以拓展专业视野，了解科研前沿动态，促进专业知识的理解和运用，提高学生的逻辑思维能力和表达能力，有利于综合素质的提高。

3）根据报告的目的，学术报告可以分为科普型、综述型或专题型、个人成果汇报型和讨论型。科普型报告的目的是向外行普及某方面的科学知识，因此报告深度较浅，应尽量少用专业术语。综述型或专题型报告是向同行专家、学者、老师或同学讲述本领域或本专业某一研究方向或某种科学技术的研究进展情况，听众对本领域专业知识和科学技术较为熟悉，因此需要注意表达的专业性，并关注专业细节。个人成果汇报是展示自身在科研、项目、学

习等方面的成果，因此需要突出个人的学习、工作或科研成果、成绩或效果。讨论型报告的目的是解决特定问题而征集建议，形成决议，因此需要将问题表达全面、条理、清晰，便于大家展开讨论。

4）根据报告使用的语言也可以对学术报告进行分类。国内学术交流通常采用母语，且听众的文化背景和思维方式和报告人较为接近，交流沟通较为容易。而国际学术交流通常采用英文学术报告，听众的文化背景和思维方式存在差异，因此报告人除了要掌握学术报告的制作方法和技巧外，还需要适应听众的文化背景和思维方式，掌握好专业英语，并灵活运用。

此外，学生进入社会还会经历很多职场报告，如面试报告、竞聘报告、就职报告、述职报告、项目报告、调查报告、产品报告等。学生阶段掌握的学术报告准备方法和由此获得的各方面能力提升有助于入职后成功驾驭上述报告，获取更多发展机会。

13.1.3 学术报告的基本要求

学术报告表达形式多样，可以利用图表、文字、语言、视频、肢体语言及现场演示等各种方式对重点内容反复强调，加深印象。报告人可以和同行、专家面对面交流，获得及时的反馈并现场解决或修正问题，有利于激发科研思路。但是学术报告是即时的，听众没有时间详细了解报告内容的背景，只能按照报告人的汇报思路和进度了解报告内容。因此，报告人的报告设计和演讲能力直接决定了自身学术成果展示和学术交流的成败。做学术报告的第一步就是要了解学术报告的基本要求，在制作报告和汇报过程中尽量遵循，以达到报告预期效果，避免负面影响。

（1）内容要求　完整性、逻辑性、科普性和客观性。

完整性：任何学术报告必须在结构上达到完整性要求，组成包括标题、报告人/单位及完成人/日期、内容提纲、背景介绍、主要技术或成果介绍、致谢（包括主持人、邀请人、合作者、资助者及听众）。

逻辑性：突出重点，论点明确，详略有致；避免纠缠于细节，尤其是过细地讲述数学公式的推导，听起来让人昏昏欲睡。论据充分，言之有据，调理清晰，使听众感到无懈可击；避免脉络不清，概念含糊，演绎粗疏，无法令人信服。具体操作时，需使报告所有的内容和环节都紧扣主题，围绕目的和意义、研究进展、问题提出（创新的体现）、解决思路和方法介绍、结果及结论，一步步展开论述和汇报。

科普性：从听众的角度出发，尽最大努力使他们能轻松地、清晰地跟踪和理解报告的思路和逻辑，因此报告必须深入浅出、鲜明生动，使多数听众听得懂，避免讲述过于艰深、堆砌专业术语，把听众搞得一头雾水。

客观性：报告呈现的内容不论是以何文字、图表还是其他形式表达，都必须真实客观，这既是对科学的尊重、对同行的尊重，也是影响报告质量和可信度的重要因素。

（2）形式要求　多样性、规范性、简洁性和美观性。

多样性：前已述及，学术报告与论文相比的优势之一就是可以借助多种表达方式提升报告效果。学术报告中常用的表达形式有文字、照片、数据图表、框图或流程图、视频、语言、实物展示、现场演示等。报告人可根据实际情况，将多种表达方式结合起来使用，加深听众印象，尤其对于关键问题的说明过程，可借助多种方式反复强调。

规范性：规范的幻灯片能反映出报告人严谨的科研态度，从而有助于提高报告内容的可

靠性。具体要求包括：演示文稿的整体风格和背景模板统一，文字和图表符合学术论文的规范性要求，如首字母大写，正确使用标点符号，规范引用参考文献，前后表达一致等，图表要素表达清晰，图题和表头标注明确等。

简洁性：演示文稿版式简洁、动画特效简单，不要喧宾夺主；避免使用多种颜色和多种字体；文字要言简意赅、条理清楚、大小清晰可见，尽量放短句或词组，避免大幅文字；图表清晰、关键数据可读；幻灯片内容较多时，可设置动画依次呈现或圈出讲解要点。

美观性：在保证真实、客观、严谨的基础上采用生动地表达、绘制美观、简洁的示意及数据图表、插入形象生动地卡通图画和照片和合理排版每张演示文稿的内容等途径都可以提高演示文稿的“可读性”、吸引听众的眼球，但是千万不要将演示文稿做的过于花哨而令人生厌。

（3）表达要求　生动性、守时性、灵活性和客观性。

生动性：音量适当，如用扩音设备应注意保持适当距离，避免声音忽大忽小或产生噪声；避免言辞啰唆，讲述拖沓，言不及义，布局不当；控制语速和演示文稿播放速度，即使演示文稿可读性好、讲话清晰，讲述一张演示文稿的时间也不要超过一分钟；辅以适当的肢体语言，不要太呆板，但是避免过多小动作；注意与听众的眼神交流，利于了解听众的状态以及和他们产生共鸣。

守时性：控制幻灯片数量，突出亮点，抓大放小，精准练习，严格把握时间，免得意犹未尽而被赶下台。

灵活性：灵活应对演讲和回答问题环节可能出现的各种状况，如设备故障、中途打断等情况。

客观性：表述报告内容和评述他人成果时客观准确，不夹杂个人感情和主观臆断，对提问者的问题进行客观、如实回答。

（4）准备要求　充分准备，按步骤做好每个环节，才能保证成功地完成一场英文学术报告，图 13-1 所示为英文学术报告的准备流程，本章将根据该准备流程顺序展开介绍。

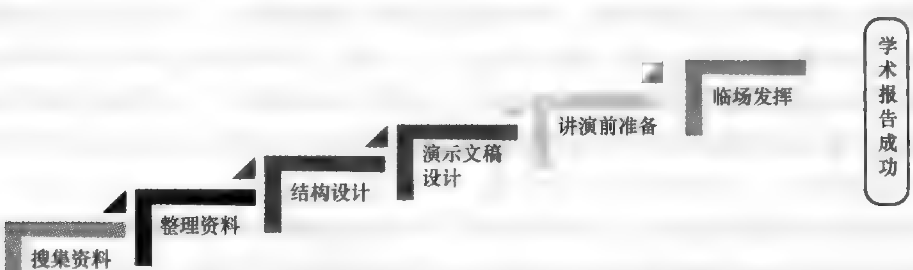


图 13-1　英文学术报告的准备流程

13.2　学术报告的资料搜集与整理

13.2.1　文献资料搜集的意义

学术研究是为了探求事物的内在规律，而规律总是隐藏在大量的现象和纷繁的材料之中，正如达尔文所说“科学就是整理事实，以便从中得出普遍规律或结论”。因此充分地占

有资料，是写好学术论文、做好学术报告的一个必不可少的环节。对于科普型和综述型/专题型学术报告，搜集的资料是报告内容的素材来源和基础，因此资料是否全面、实时直接决定报告内容的质量。对于个人成果展示型报告和讨论型报告，无论报告人在之前的研究过程中是否进行过资料搜集工作，都需要在与同行交流之前进行一次资料搜集工作，以核实自身研究成果或所提问题的正确性和实时性，避免自身的研究误区影响报告效果。

学术报告的素材可以通过观察、实验、查阅文献等途径获得，其中查阅文献是学术报告素材搜集的必要手段。凡是人类知识用文字、图形、符号、声频、视频等手段记录下来的、有长远历史价值和当前利用价值的东西，统称为文献。搜集文献资料通常称为检索文献资料，是从汇集的文献资料中选出既定需要的资料的操作过程，其重要性体现在如下几个方面：

1）有助于了解前人对所研究问题的见解，避免走弯路、闭门造车。任何学习和研究工作都要从现有的基础出发，继承前人或同辈在这个问题上所获得的宝贵成绩，吸取他们的成功或失败的宝贵经验。同时，深入了解了本学科的研究历史和进展，才能确定所研究的问题、报告的主题是否具有理论意义或实践价值。

2）有助于选择、缩小或调整报告主题。学术报告的准备工作不是在搜集完资料后才开始的，应该是边搜集材料，边修改主题，进一步调整搜索范围。搜集材料的过程也是形成观点的过程，是从选题到命题形成的过程，因此是明确目标、增加深度的重要环节。命题的一般过程为：兴趣点（大致方向）→划定报告内容范围→确定具体主题。只有搞清楚目前已出版的、与兴趣点有关的文献资料的情况，才能将报告主题的焦点缩小到恰当的范围。如果选题太宽，文献量太大，报告的内容会肤浅；而如果主题定的太窄，文献太少，则报告内容就会过于单一。

3）有助于提炼学术观点，支撑学术创新，升华学术报告效果。学术观点是研究成果的核心内容，一切有价值的学术观点不是凭空杜撰出来的，而是研究者在充分占有资料的基础上，对资料进行认真分析和研究的结果。无论是何种形式的学术报告，都必须展示凝练的学术观点，即使是综述型报告也需要在前人成果综述的基础上，提炼出自己的看法。因此是否凝练出学术观点是决定学术报告深度和水平的重要因素。同时，学术观点必须由材料支撑，观点与材料是两个互相依存的要素，一个好的学术报告中观点与材料应该是有机统一在一起的，即观点统帅材料、材料支撑观点。

13.2.2 文献资料搜集的要求

搜集文献资料，要遵循以下原则：定向、充分、真实、新颖和及时记录。

1）定向：确定搜集范围，紧紧围绕当前课题、专业兴趣点或主题，拟定文献搜集大纲，明确搜集目的、内容、时间界限和文献类别，以节省时间和精力。一般来说，搜集的文献范围包括：与论题相关的已有研究成果，如已出版的著作和已经发表的论文等；与论题相关的学科基本理论知识，因为扎实的基础理论知识是学术论文和报告内容的基础；论题相关学科的研究成果，包括横向比较的资料和相关的背景资料。

2）充分：收集资料要全面，要全方位、广泛地涉猎资料，历史的、现实的、正面的、反面的、点上的、面上的、远的、近的都要搜集。强调占有基础性资料、前沿性资料和灵感性资料，并抓住重点，切忌“丢了西瓜捡芝麻”。

3）真实：收集第一手资料，而不是经过几次转引的资料，以保证准确性和公正性，并具有较强的说服力。

4）新颖：需要了解最新动态，搜集最新资料，以免重复前人的工作，丧失研究的意义、降低报告的时效性。

5）及时记录：根据文献内容，融入自己的思考和想法，做好文献摘录、标注和笔记，并进行分类，使文献资料活起来，便于今后查阅和保存灵感。

13.2.3 文献资料的类型

传统的图书馆是专用于典藏书籍的处所，其收藏的主要是纸质文献。随着科学技术的迅速发展，现代的记录形式和出版方式有了很大变化，“图书”这个概念已经不能概括当前所有的出版物。今天，人们将数据、期刊、资料等不同出版物统称为文献，且文献既可是纸质印刷形式，也可以是电子版本（数字资源）。图 13-2 所示为根据编辑出版形式对文献的分类，各种文献的具体定义如下：

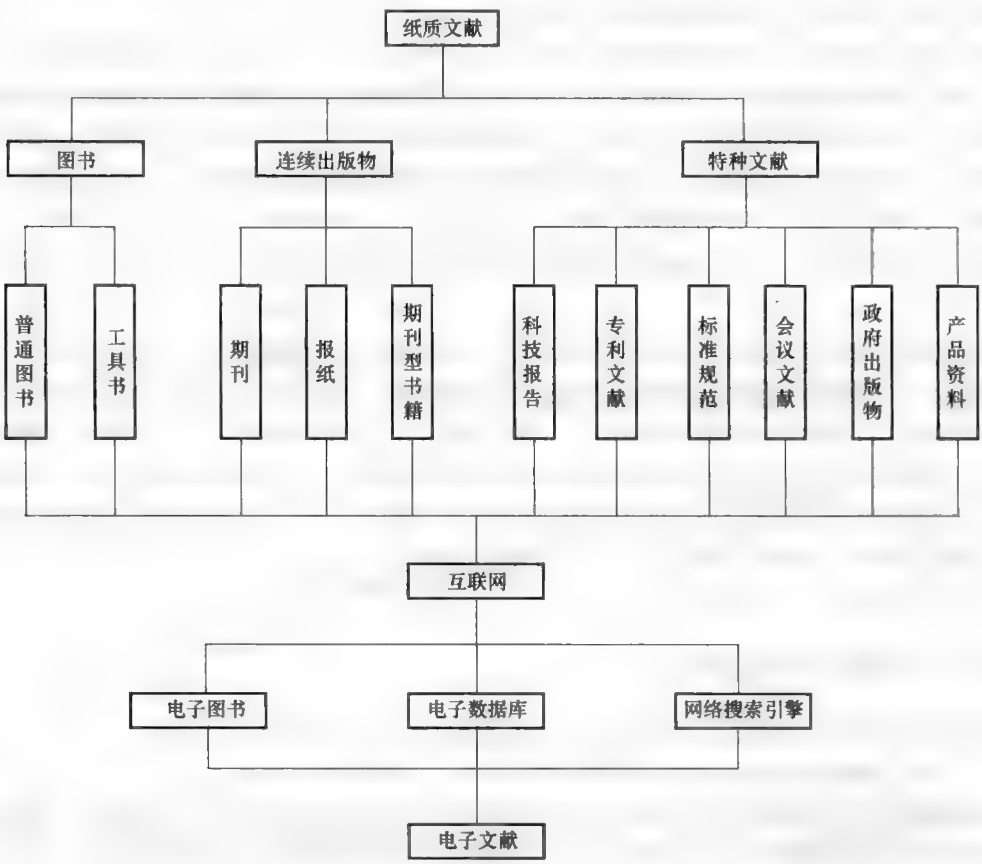


图 13-2　根据编辑出版形式对文献的分类

（1）图书　图书（Book）是指内容比较成熟，资料比较系统，有完整定型的装帧形式的出版物。

（2）工具书　工具书（Reference book）是人们根据一定的目的全面系统地搜集某一方

面或专业领域的有关资料，经过筛选、加工整理、概括、浓缩等手段，用一定的编排方法加以组织编排，专供查考问题和数据、检索文献线索的一种特种图书，如字典、词典、百科全书、年鉴、手册等都属于工具书。

（3）期刊　期刊（Journal/Periodical）是指逐次刊行，通常有数字或年月顺序编号，并连续出版的出版物，但每期刊物都有固定的刊名。

（4）科技报告　科技报告（Report/Technical report）是科学技术工作者围绕某个课题研究所取得成果的正式报告，或对某个课题研究过程中各阶段进展情况的实际记录。绝大多数科技报告涉及高、精、尖科学研究和技术及其阶段进展情况，能够客观地反映科研过程中的经验教训。

（5）会议文献　会议文献（Conference paper）是在各种学术、专题会议上发表的论文和报告，多以会议录、论文集的形式出现，是专业领域最新研究成果报道的一种主要方式。

（6）专利文献　专利文献（Patent document）是指发明人或专利权人申请专利时向专利局呈交的一份详细说明发明目的、构成及效果的书面技术文件，经专利局审查，公开出版或授权后的文献。

（7）标准文献　标准文献（Standard/Specification/Requirement）是指经过公认的权威机构批准的以文件形式表达出的统一规定，包括技术标准、技术规格和技术规则等文献。

（8）学位论文　学位论文（Dissertation/Thesis）是指高等学校或研究机构的学生在导师指导下从事某一学术课题的研究，为获得某种学位而撰写的学术性较强的研究论文。

（9）政府出版物　政府出版物（Government document）是各国政府部门及其所属机构发表、出版的文件，其内容广泛，可以分为行政性文献和科技文献两大类。

（10）产品资料　产品资料（Product literature）是指各厂商为推销产品而印发的商业宣传品，包括产品样本、产品目录、产品说明书、厂商介绍、技术座谈资料等。

此外，根据文献的结构等级即文献的加工程度可以将文献分为三个结构等级：

一次文献（Primary document）：即原始文献。是指人们以自己的经验和研究成果为依据而形成的文献，如期刊论文、会议论文、科技报告、专利说明书、标准等。一次文献的信息比较具体、详尽和系统化。

二次文献（Secondary document）：是指通过对大量分散、无序的一次文献进行加工、提炼、压缩和组织，成为系统的、便于查找一次文献的工具。例如书目、索引、文摘等检索工具就是二次文献，通过二次文献可以找到一次文献的重要线索。

三次文献（Tertiary document）：在利用二次文献的基础上，对检索到的一次文献进行广发、深入的分析研究之后，再次加工出来的成果，如综述、述评、进展等。

13.2.4　文献资料的检索

文献资料的检索即是文献资料的查找。熟悉文献资料检索的途径，掌握文献检索的工具和方法，按照文献资料检索的步骤，才能快速、准确地收集所需的资料信息。

1. 检索途径

（1）分类途径　分类途径是指按照文献资料所属学科（专业）类别进行检索的途径，它所依据的是检索工具中的分类索引。

（2）主题途径　主题途径是指通过文献资料的内容主题进行检索的途径，它依据的是

各种主题索引或关键词索引，检索者只要根据项目确定检索词（主题词或关键词），便可以实施检索。主题途径检索文献关键在于分析项目、提炼主题概念，运用词语来表达主题概念。主题途径是一种主要的检索途径。

（3）著者途径　著者途径是指根据已知文献著者来查找文献的途径，它依据的是著者索引，包括个人著者索引和机关团体索引。

（4）题名途径　该途径是指通过文献的题名来查找文献的途径。题名包括文献的篇名、书名、刊号、标准号、数据库名等，检索时可以利用检索工具的书名索引、刊名索引、会议论文索引等进行。

（5）机构途径　该途径是指通过机构名称获取相关信息、了解该机构情况的途径。以机构途径检索文献，一般以计算机检索工具为主，手工检索少用。

（6）代码途径　代码途径是通过信息的某种代码来检索信息的途径。例如，图书的ISBN号、期刊的ISSN号、专利号、报告号、合同号、索书号等。

（7）其他途径　其他途径包括利用检索工具的各种专用索引来检索的途径。专用索引的种类很多，常见的有各种号码索引（如专利号、入藏号、报告号等），专用符号代码索引（如元素符号、分子式、结构式等），专用名词术语索引（如地名、机构名、商品名、生物属名等）。

2. 检索工具

检索工具是用于存储、查找和报道档案信息的系统化文字描述的工具，是目录、索引、指南等的统称，具有如下特点：详细描述文献的内容特征、外表特征；每条文献记录必须有检索标志；文献条目按一定顺序形成一个有机整体，能够提供多种检索途径。根据著录内容，检索工具可以分为四种：目录、题录、文摘和索引。

（1）目录　目录（Catalog）是对一批相关文献外部特征（如名称、著者、出版事项等）的揭示和报道，通常以一个完整的出版或收藏单位为著录的基本单位来报道和记录文献。目录一般按分类或字顺编排，主要供人们了解出版或收藏机构是否拥有所需图书、期刊等出版物。例如馆藏目录、图书目录、期刊目录、联机公共检索目录等，目录示例如图13-3所示。

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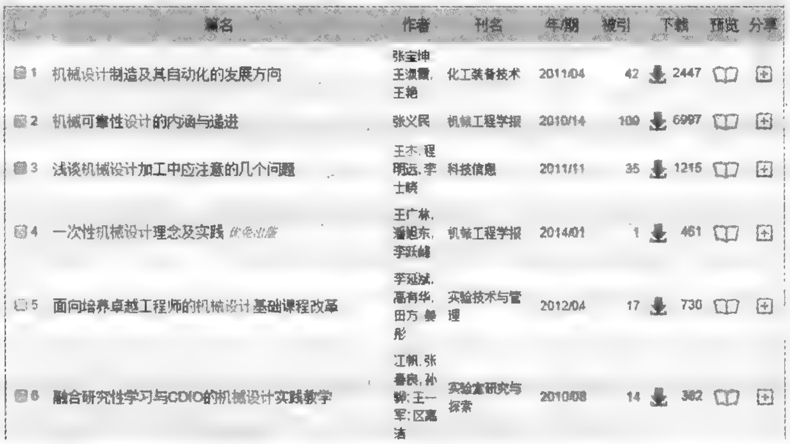
图13-3　目录示例（截自Cnki，《中国机械工程》，2015，第7期）

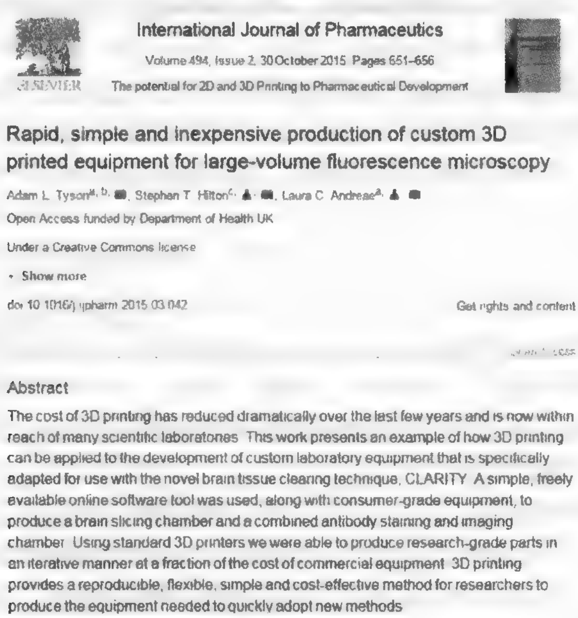
（2）题录 题录（Bibliography/Bibliographic/Citation）是将图书和报刊中论文的篇目按照一定的排检方法编排，供人们查找篇目出处的工具。题录的著录项通常包括篇名、著者、来源出处和无内容摘要等。题录在揭示文献内容的深度方面，比目录深入，但又比文摘简单，示例如图 13-4 所示。



	篇名	作者	刊名	年/期	被引	下载	预览	分享
1	机械设计制造及其自动化的发展方向	张宝坤 王淑霞，王艳	化工装备技术	2011/04	42	2447		
2	机械可靠性设计的内涵与递进	张义民	机械工程学报	2010/14	100	6997		
3	浅谈机械设计加工中应注意的几个问题	王杰.程明远.李士晓	科技信息	2011/11	35	1215		
4	一次性机械设计理念及实践 优先出版	王广林，潘旭东，李跃峰	机械工程学报	2014/01	1	461		
5	面向培养卓越工程师的机械设计基础课程改革	李延斌，高有华，田方，黄彤	实验技术与管理	2012/04	17	730		
6	融合研究性学习与CDIO的机械设计实践教学	江帆.张春良.孙骅;王一军;区嘉洁	实验室研究与探索	2010/08	14	382		

图 13-4 题录示例（截自 Cnki）

（3）文摘 文摘（Abstract）是指对一份文献（或称一个文献单元）的内容所做的简略、准确的描述，文摘的著录项目除了著者、篇名及出处等外，还有表示文献内容特征的摘要，示例如图 13-5 所示。



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The potential for 2D and 3D Printing to Pharmaceutical Development

Rapid, simple and inexpensive production of custom 3D printed equipment for large-volume fluorescence microscopy

Adam L. Tyson[a, b], Stephan T. Hilton[c], Laura C. Andreae[a]

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Abstract

The cost of 3D printing has reduced dramatically over the last few years and is now within reach of many scientific laboratories. This work presents an example of how 3D printing can be applied to the development of custom laboratory equipment that is specifically adapted for use with the novel brain tissue clearing technique, CLARITY. A simple, freely available online software tool was used, along with consumer-grade equipment, to produce a brain slicing chamber and a combined antibody staining and imaging chamber. Using standard 3D printers we were able to produce research-grade parts in an iterative manner at a fraction of the cost of commercial equipment. 3D printing provides a reproducible, flexible, simple and cost-effective method for researchers to produce the equipment needed to quickly adopt new methods.

图 13-5 文摘示例（截自 Sciencedirect）

（4）索引 索引（Index）是将书刊内容中所论及的篇名、语词、主题等项目，按照一定的排检方法加以编制，注明出处，供读者查检使用的检索工具。索引与目录的根本区别在

于著录的对象不同：目录所著录的是一个完整的出版单位，如一种图书、一种期刊等；索引所著录的是完整的出版物的一部分、某一观点或某一知识单元。因此索引能解决目录只对文献做整体的宏观著录的不足，满足读者对文献内容单元的微观揭示和检索的要求，提高文献检索的深度和检索效率。例如图书《二十四史纪传人名索引》将《二十四史》各人名索引汇集在一起，检索极为方便。

3. 网络信息检索工具——搜索引擎

搜索引擎（Search Engine）是一些在网页中主动搜索信息并将其自动索引的 Web 网站，与普通网站不同的是，搜索引擎网站的主要资源是它的索引数据库，收集了全世界成百万上千万个网站和网页的信息，存储在可供检索的大型服务器中，建立索引和目录服务。搜索引擎是充分利用各种网络自动搜索技术，对网络信息资源提供强有力检索的工具。常用的搜索引擎有百度（Baidu）、雅虎（Yahoo）、谷歌（Google）等。

4. 国内外常用电子期刊数据库简介

（1）国内主要电子期刊数据库　中国知网（CNKI）（http：//www. cnki. net/），全称中国知识基础设施工程（China National Knowledge Infrastructure，CNKI），是由清华同方光盘股份有限公司、清华大学中国学术期刊电子杂志社、光盘国家工程研究中心联合建设的综合性文献数据库。目前 CNKI 已建成了中国期刊全文数据库、优秀博硕士学位论文数据库、中国重要报纸全文数据库、重要会议论文全文数据库、科学文献计量评价数据库系列光盘等大型数据库产品，中国期刊全文数据库为其主要产品之一。

中文科技期刊数据库/维普数据库（VIP）（http：//www. cqvip. com/），按照《中国图书馆图书分类法》进行分类，所有文献被分为 7 个专辑：自然科学、工程技术、农业科学、医药卫生、经济管理、教育科学和图书情报，7 大专辑又进一步细分为 27 个专题。

万方数据知识服务平台（wanfangdata）（http：//www. wanfangdata. com. cn/），由万方数据股份有限公司开发，集纳了涉及各个学科的期刊、学位、会议、外文期刊、外文会议等类型的学术论文，法律法规，科技成果，专利、标准和地方志，收录自 1998 年以来国内出版的各类期刊6 千余种，其中核心期刊2500 余种，论文总数量达一千余万篇，每年约增加200 万篇，每周两次更新。

中国科学引文数据库（CSCD），创建于 1989 年，1999 年起作为中国科学文献计量评价系列数据库（ASPT）的 A 辑，由中国科学院文献情报中心与中国学术期刊电子杂志社联合主办，并由清华同方光盘电子出版社正式出版，是我国最大、最具权威的科学引文索引数据库——中国的 SCI。CSCD 收录了国内数学、物理、化学、天文学、地学、生物学、家林科学、医药卫生、工程技术、环境科学和管理科学等领域的中英文科技核心期刊和优秀期刊，其中核心库来源期刊为 650 种。

（2）国外主要电子期刊数据库　美国 EBSCO 数据库（http：//ejournals. ebsco. com），EBSCO 公司从 1986 年开始出版电子出版物，共收集了 4000 多种索引和文摘型期刊和 2000 多种全文电子期刊。该公司含有商业资源电子文献库、学术期刊全文数据库等多个数据库。学术期刊集成全文数据库包括有关生物科学、工商经济、资讯科技、通信传播、工程、教育、艺术、文学、医药学等领域的七千多种期刊，其中近四千种全文刊。

美国 ProQuest 数据库（http：//proquest. umi. com/），即博士学位论文全文数据库收录的是世界著名的学位论文数据库 PQDD（ProQuest Digital Dissertations）数据库中部分记录的

全文，收录有欧美 1000 余所大学文、理、工、农、医等领域的博士、硕士学位论文，是学术研究中十分重要的信息资源。

美国 Wiley InterScience 数据库（http：//www. interscience. wiley. com），是 John Wiely & Sons 公司创建的动态在线内容服务，1997 年开始在网上开通，收录了 360 多种科学、工程技术、医疗领域及相关专业期刊、30 多种大型专业参考书、13 种实验室手册的全文和 500 多个题目的 Wiley 学术图书的全文。其中被 SCI 收录的核心期刊近 200 种。

美国 Isiknowledge/SCI 数据库（http：//www. isiknowledge. com），收录最重要的学术期刊和收录论文的参考文献并索引。SCI 覆盖农业、天文学与天体物理、生物学、化学、计算机科学、生态学、工程、环境科学、食品科学与技术等 150 多个学科领域，收录期刊每一期每一篇文献。

美国 IEEE 数据库（http：//www. ieee. org），IEEE（Institute of Electrical & Electronics Engineers）是电子信息领域最著名的跨国性学术团体，其会员分布在世界 150 多个国家和地区。通过 IEEE Xplore 与 IEEE/IEE Electronic Library（IEL）连接，IEEE 为会员提供更加完善和全面的电子信息产品和服务。IEL 包括了 1988 年以来 IEEE 和 IEE 的所有期刊和会议录，以及 IEEE 的标准，可以通过题目、关键词和摘要进行查阅。

荷兰 Sciencedirect 数据库（http：//www. sciencedirect. com），荷兰 Elsevier Science 公司出版的期刊是世界上公认的高品位学术期刊，它拥有 1263 种电子全文期刊数据库，并已在清华大学图书馆设立镜像站点：ScienceDirect OnSite（SDOS）。国内 11 所学术图书馆于 2000 年首批联合订购 SDOS 数据库中 1998 年以来的全文期刊。包括 2200 多种期刊，780 多万篇全文，包括在编文章；2000 多种图书，包括常用参考书、系列丛书、手册；6000 多万条摘要。涉及农业和生物科学、化学工程学、化学、计算机科学、能源和动力、工程和技术、环境科学等多种学科。

德国 Springer LINK 数据库（http：//link. springer. com），是著名的德国科技出版集团施普林格（Springer-Verlag）提供的学术期刊及电子图书的在线服务。目前 Springer LINK 所提供的全文电子期刊共包含 439 种学术期刊（其中近 400 种为英文期刊），涵盖生命科学、医学、数学、化学、计算机科学、经济、法律、工程学、环境科学、地球科学、物理学与天文学等学科，是科研人员的重要信息源。

13. 2. 5 文献资料的整理与使用

1. 资料归类的方法

收集完资料后，需要对其进行分门别类的处理，才能使纷纭的材料条理化，便于使用。在对资料归类的过程中，人们总结出一些方法，常用的如按事物发展的阶段来整理资料的“阶段法”，按一个问题的几个方面来整理资料的“方面法”，按一定观点划分资料的“观点法”，按材料本身的属性划分的“内质法”等。分类时一次只能采取一个方法，以免造成分类体系和层次的混乱。下面介绍几种辅助资料分类的方法：

（1）标记或眉批 在精读著作的空白处写上自己的见解、评语、解释或质疑等，记录阅读当时的想法，在重点、难点、创新点等位置画上各种记号。

（2）抄录或复印 在卡片或笔记本上记下原文的重要观点、方法等重要材料，以作为自己今后论证、引证时用，篇幅太长也可以采用剪报、复印等方式。摘录时一定要注明出

处，方便今后核查原文。使用卡片搜集资料，具有易分类、易保存、易查找的特点。做笔记时，最好空出一定的纸面空间，以供写自己对有关摘录内容的即时理解、体会和评价。剪报或复印后，将资料贴在笔记本或卡片上，可以节省书写时间。

（3）归纳　把原文的基本内容、主题、观点、独到之处等用自己的话加以总结概括，有利于激发创作灵感。

（4）札记和文献综述　做札记就是随时记下自己阅读文献时的心得体会和感悟，做文献综述是对文献经过阅读、筛选、归类、思考，形成自己的看法和观点，并把这些看法和观点用自己的话表达出来的过程。文献综述中引用到别人的成果必须标注。

2. 资料的辨析与整理

资料的整理过程实际上是资料的辨析过程，需要从以下 4 个方面着手：

（1）辨析资料的适用性　选择资料的目的是服务于中心论点或观点，因此什么资料可用，什么资料不能用，都必须由中心论点决定。中心论点或观点一经确定后，资料必须服从其统帅，从多个方面对其进行服务。不能充分说明问题的资料应当坚决摒弃，否则会造成报告臃肿庞杂、中心不突出、调理不清晰。

（2）辨析资料的真实性　搜集到的资料真实与否直接关系着报告的成败，因为我们只有从真实可靠的资料中才能获得科学的观点和结论。判定资料真实性时需要注意：①要尊重客观实际，避免先入为主的思想，不能夹杂个人的主观好恶或者偏见，不能随意歪曲资料的客观性；②选择资料时要有依据，第一手资料要有来历，第二手资料一定要与原始文献一致；③对资料的来源要加以辨别，清晰作者的写作意图，不要断章取义。

（3）辨析资料是否新颖和典型　所谓新颖的资料是指前所未有的新事物、新方向、新方法、新发现。新颖不仅对资料的产生时间有所要求，更重要的是从普遍常见的资料中挖掘出别人尚未利用的东西。典型性是指资料对于它所证实的理性知识来说具有充分的代表性，具有无可辩驳的逻辑力量和说服力。识别资料的基本方法之一是将资料互相联系起来做比较，鉴别资料和数据的新颖性和典型性，选取新颖的、典型的资料。对于选定的资料也要选择其精华之处、独到之处，选取代表性强、可信度高的部分；或者选择其欠缺、不足之处或有争议之处，增补自己的观点。

（4）辨析资料的全面性　最后需要对资料再进行整体审视，确定各类材料是否均衡，有无重复、薄弱环节及遗漏。需注意下面四个“是否”：是否全面、充分地占有了资料，是否占有了最重要的、关系最密切的资料，是否占有了最典型的、有代表性的资料，是否占有了变化发展、互相联系、不同看法的资料。材料多而全是最理想的，缺少了某一方面的材料，报告的内容也往往不圆满、不全面，会出现偏颇、漏洞，或由于证据不足而难以自圆其说，如果材料不足需要再收集补充。

3. 资料的使用

经过归类、筛选和整理之后，就可以针对性地使用资料，为主题服务了。使用资料时应注意以下几个方面：所选用的材料需具有很强的代表性，可以代表没有使用的大多数材料；尽量使用直接论据材料，但是避免堆砌性质相同的论据；在引用材料时切忌断章取义，如在摘引一篇文章或者一段比较长的文字时，必须弄清楚这段材料与上下文之间的关系，以确定摘引材料作者的原意。具体使用时，可参考下列方法：

（1）主次互补法　利用几个相同或相近的资料集中起来统一论证某一论点，但要选好

主材料和次要材料，处理好它们与论点之间的关系。主材料是从正面论述论点的，要有足够的文字，且需对其与论点的关系进行详细的论证。主材料至关重要，只要提出了一个比较重要的观点，都需要主材料作为论据的支撑，没有主材料，最好不要列论点。次要材料使用时可以摘句，概括大意，或者举出篇名或出处。主次分明、互相补充，既显得材料充实，又能具体突出使论证饱满而有立体感。

（2）对比法　运用具有同一属性但相反的资料，从正反两面去论述某一论点。正确处理反例材料，即观点是相对立或内容是相反的材料，学会消化这些不利的材料即说明为什么会存在这些不利材料，分析它们对论点和结论有什么影响。

（3）新视角法　从新的视角看待文献或用新的方法分析文献，衍生出新的观点或观点的支撑论据。

（4）一材多用法　在一个学术报告中可以多次使用同一资料来论述，但要注意每次强调的重点不同，论述的侧重点也不同。

13.3 学术报告的结构

学术报告的结构是决定其是否成功的关键因素。学术报告的结构包括主要论点的组织、论点之间的转换衔接、论述的深度以及细节的强调。学术报告的结构在很多方面与学术论文是很相似的，如以实验为主的学术报告需要以实验简介和实验结果及分析作为其主要内容，以理论分析为主的学术报告需要以分析方法简介和分析方法验证作为其主要内容。但是学术报告的结构还需要适应学术报告自身的特点，在有限的时间内最大程度吸引听众、产生共鸣，才能实现预期的报告效果。

13.3.1 学术报告结构设计要点

1. 报告结构和内容与听众匹配

你的听众是怎样一个群体？这一点至关重要，决定了报告的表述方式、内容深度，以及你要带给听众什么样的信息。同样的内容，针对不同知识结构的听众，讲述方法和传递的信息完全不同，甚至有天壤之别。如果是科普报告，需要将科学的语言和内容，转换成通俗易懂的内容，达到普及科学知识的目的；如果是学术会议报告，则需适当地介绍研究的意义和背景，便于学科相近的同行或交叉学科同行的理解；如果是同行或课题组的学术交流，则可以直奔主题、简化背景和意义甚至省略，侧重于研究方法和结果。

2. 逻辑性强、前后连贯

做学术报告时不必按照学术论文的结构从引言到结论依次全面叙述，主要应该明确研究主旨、展示思维逻辑、逐步展开层次、突出创新成果、讲清基本观点。报告内容的前后连贯性要好，听起来像是讲一个故事，需要设计好情节的顺序并保证情节环环相扣。例如，我要讲什么（问题的定义）—为什么讲（意义）—按照什么步骤讲（大纲）—已有解决方案及缺陷（背景）—我们如何解决（详解）—解决的结果及讨论（详解）—比较优点—阐述不足及未来研究方向。

3. 重点突出、严控时间

一个成功的学术报告，应该重点突出，让听众能够对关键内容留下深刻印象。其结构不

应该局限于学术论文模式，避免发散性思维模式，应该开门见山提出观点并用充分的论据多次强调。一些细节或次要的内容如公式的推导过程除非非常重要，可以不详述，因为复杂的公式推导不仅枯燥而且很难给听众留有印象。

13.3.2 学术报告的一般结构

一般来讲，一个学术报告包括以下部分：

（1）题目　学术报告一般设置题目页作为报告的首页，在题目页中除了显示报告的题目之外，还显示作者的信息（姓名、单位、联系方式等）、报告的场合（如参加的学术会议名称）、报告时间等关于学术报告的基本信息。

（2）大纲　依据报告的主题制定一个大纲，来组织结构并帮助听众了解各部分内容的内在联系。一般大纲放在标题页之后作为单独的一页，大纲中每部分的标题文字要概括且所有标题的文法结构要统一。例如都是动词短语或都是名词短语等，不要交叉使用而影响表达的工整性。以下（3）~（5）点部分的标题都应该列在大纲页上，为了帮助观众梳理思路，也可以在每部分之前再加设一次大纲页。

（3）意义和背景介绍　用于阐述学术研究的意义、发展概况、存在的问题，作用相当于学术论文的引言。意义和背景的面要宽，能够清楚地向读者介绍所在领域的现状及研究的意义和重要性。但该部分内容应简略，不宜过多过细，同时体现出研究内容的价值，便于之后顺理成章地引出自己的研究内容。

（4）主体部分　背景介绍之后就可以逐步将视野缩小到所研究的具体问题上，这是报告的主体部分，即核心部分。该部分需要对关键内容尤其是创新之处进行详述并重点强调，借助文本、图表、照片等多种形式表达研究问题、方法、结果和讨论。

（5）结论　结论用于高度概括报告涉及的主观点、研究结果升华的结论、创新点等关键内容，可以对重点内容或重要发现起到强调作用，并加深读者对报告主要内容的理解和印象。

（6）致谢　致谢位于报告的末页，感谢所有嘉宾和听众的参与，并欢迎他们的宝贵建议和提问。

13.3.3 几种典型的学术报告主体结构

本章13.3.2节中介绍的报告组成部分中，（1）~（3）点及（6）点是每个报告的必备部分，4点是报告的主体部分，因报告的场合、类型而不同。下面介绍几种典型报告的主体结构，在报告设计时可作为参考。

（1）以实验为主的学术报告　实验简介、实验结果及讨论、结论。

（2）以理论分析为主的学术报告　分析方法简介、分析方法验证、结论。

（3）综述类专题报告　综述类专题报告的主体结构取决于综述材料的主线或思路，如报告主线是某技术的发展过程或历史，主体结构可以根据阶段划分；报告主线是某技术的分类，主体结构可根据主要类型进行划分；报告主线是按照区域，如国内外或不同国家的进展情况，则可以根据相应区域进行划分；报告主线是应用领域，则可以根据典型领域进行划分。

（4）开题报告　开题报告又名研究方案，是实施研究前关于整个研究的重要性、必

要性、可行性的论证及对研究内容和整个过程的构思、策划和安排。硕士或博士的开题报告需要以学术报告的形式汇报，经过专家评审通过方可开题。开题报告的主体部分应包括问题的提出，研究的主要内容与基本思路，研究的重点、难点和创新点，研究的主要方式、方法，主要参考文献，时间进度安排，预期的成果形式、经费预算及管理组织等。

（5）中期汇报报告　中期汇报报告是研究生或是科研课题执行人在科研过程中向学校或科研主管部门汇报课题研究工作进度的情况及阶段性成果的报告。其主要功能是总结前一段研究工作的成绩和经验、向相应部门汇报信息，以便检查研究进度和安排下一步工作。其主体结构一般包括课题概述（课题来源、起止时间、研究现状分析与意义、内容与方法、支持的经费等），本阶段研究工作的内容、进展情况和存在问题，所取得的阶段性成果，下阶段的研究工作计划等。

（6）结题报告　结题报告是一种专门用于科研结题或验收的实用性报告，它是研究者在课题研究结束后对科研课题研究过程和研究成果进行客观、全面、实事求是的描述，是课题研究所有材料中最主要的材料，也是科研课题结题验收的主要依据。结题报告主体结构大致包括以下部分：研究目标、研究的主要内容、研究方法、研究步骤、课题研究的主要过程、研究成果、研究存在的主要问题及今后的设想。毕业论文答辩报告也是一种结题报告，是本科生或研究生结束学业学习之前，对自己所研究课题的总结，其主体结构可参考以上结题报告主体结构设计，也可根据学校的具体要求增减内容。

13.4　报告电子演示文稿设计要求

使用电子演示文稿可以帮助演讲者清楚地表达和传递信息，因此在确定了学术报告的内容和结构之后，就需要开始着手电子演示文稿（以下简称“演示文稿”）的设计。设计演示文稿时要从演讲者和听众两个角度考虑。对于演讲者来说，演示文稿要起到提纲和提醒的作用，帮助演讲者流畅、顺利地完成报告；对于听众来说，演示文稿要清晰、简洁、易读、容易理解。再具体设计演示文稿时，应该达到以下要求：

1. 整体风格统一

演示文稿整体上应具备统一的风格，即页面的尺寸和纵横比例、版式、颜色组合、字号和字体等，在整体上要连贯、协调，避免选取多个不同风格的模板来简单地拼凑和组合。

2. 文字表述简明、准确

各页面中的题目应尽可能简洁、有效地指出该页的主题，各标题用词结构尽量对称，如都是名词短语或动宾短语等。演示文稿的文字应清楚、协调、正确，避免错别字或英文拼写错误，以免使听众认为演讲者没有认真准备；切忌使用大段文字，一方面读者没有足够的时间去阅读，另一方面会使演示文稿枯燥乏味。对于纯文字的演示文稿，正文文字每页最多6~8行，行距不小于1.2倍，每行用简洁的文字表达明确的意思或观点。由于小写字母比全部大写字母更容易阅读，因此建议在标题和正文中均尽量采用首词的首字母大写、其余均小写的形式。

3. 颜色使用协调

（1）同一页面不宜采用太多颜色　演示文稿中颜色使用十分重要，在同一页面使用不同

的色彩可达到强调重点、增强层次的效果，但同时也要注意色彩不宜太多、太杂，否则很可能会令人眼花缭乱，不知所云。在通常情况下，同一页面中的颜色不宜超过3种（图片除外）。

（2）背景和字体颜色搭配　背景色和字体颜色的色彩搭配一定要协调、美观，且要保证背景色与字体颜色有足够的对比度，以使演示文稿内容清晰可见、易于分辨，尤其对于显示效果较差的场合，更需要注意这个问题。通常深色背景（黑色、深蓝色、深褐色、大红色、深绿色等）衬托浅色字体（白色、浅黄色等），或浅色背景衬托深色字体，切忌深色字体配以深色背景。对于学术报告，推荐使用浅色（白色）背景，配以深色（黑色）字体，既能表达清晰，又不使演示文稿过于花哨，喧宾夺主。

4. 字体和字号设置得当

合适的字体、字号是演示文稿页面简明清楚的前提。英语中无衬线字体（如 Arial, Tahoma）、衬线字体（如 Times New Roman）在屏幕上更容易阅读；中文字体应优先采用宋体、华文中宋、楷体等字体；黑体字更容易阅读，尤其适用于大屏幕和大量听众的场合；一般情况下同一种语言字体不超过3种。

采用不同的字号有利于明确文字性质，大标题、小标题、正文的字号要依次减小。标题部分的字号应大于32号字，正文的字号应不小于24号，否则后排听众很难辨认。特殊情况下也可用小于24号的文字（如引用的文献、图题、表头以及次要内容等）。

5. 多用图表，增加生动性和可读性

使用图来表达时，需要注意几个方面：折线图或曲线图中尽量用符号而不是颜色来区分不同线条，相关的图例或标记要尽量直接标注在线条旁边；不常见的缩写或简称在第一次出现时一定要注明全称；坐标图中要做到坐标轴的标注明晰、各变量的含义明确、图例清楚；在图的下方尽量附有图题；采用的图应具有自明性。

表格设计要注意几个方面：设计简单、合理，内容一目了然；字号适中，可以辨认；各列数据纵向对齐，量和单位的符号要清晰、明了；表格填充颜色和文字颜色需与演示文稿版式协调；可采用的不同填充或文字颜色标注出解释重点；文字、填充颜色和演示文稿背景之间要保证合适的对比度，以清晰显示。

放在演示文稿中的图表都需说明问题，不要只是为了装饰而放置很多的图片，甚至是与主题毫不相关，否则会分散观众的注意力，扰乱思路。

6. 多用流程图和框图

为了避免演示文稿上出现大量的文字，并且清晰地展现演讲者的思路，使观众更容易理解，起到内容承上启下的作用，应提倡多用流程图或框图来表达有一定逻辑关系的内容，如分类、顺序、因果等关系。在讲述技术路线、工艺流程、编程策略等内容时，尤其适合采用流程图和框图的形式。

7. 单页演示文稿布局合理

单页演示文稿上各种形式应布局合理，避免充满页面、拥挤的文字或单一、单调的图表，最好是图文并茂。同时，为了不干扰听众的注意力，要尽量避免移动的图像、哗众取宠的图片或带纹饰的边框等。

图13-6所示为演示文稿设计不合理时产生的不良效果举例，在设计中一定要避免。图13-7所示为演示文稿设计合理时的展示效果举例，在设计中可以参考。

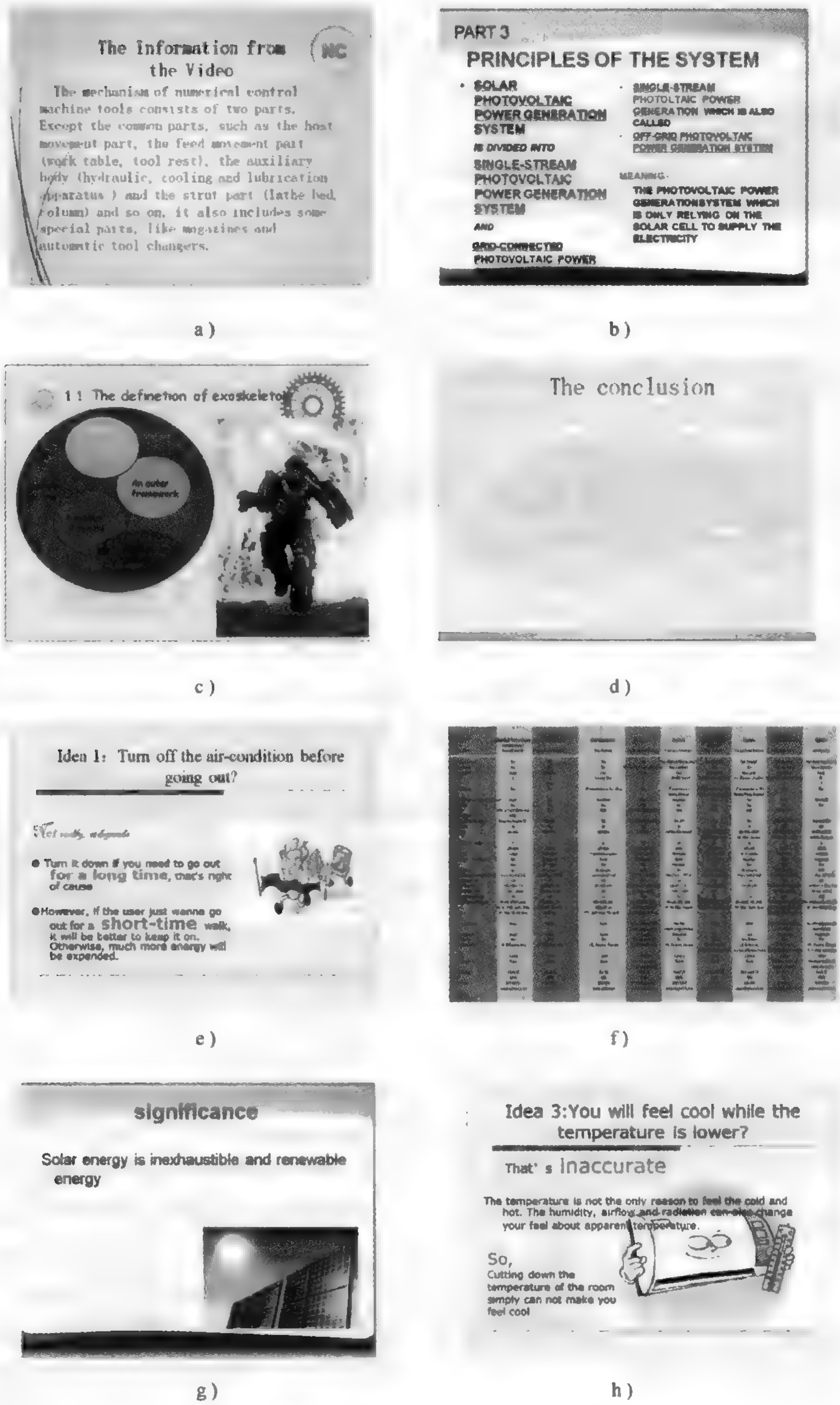
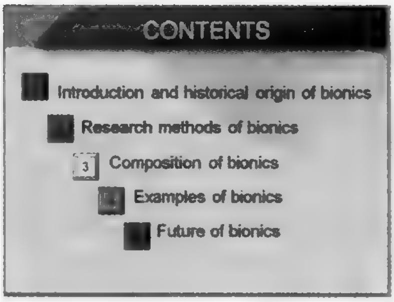


图 13-6　演示文稿制作避免效果示例

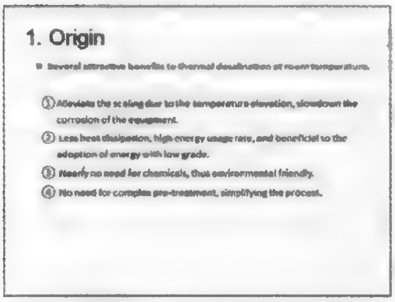
a)*大段文字　b) 全篇大写字母　c) 色彩繁杂　d) 对比度不够

e) 字体、字号混乱　f) 复杂表格　g) 页面单调　h) 图文干扰

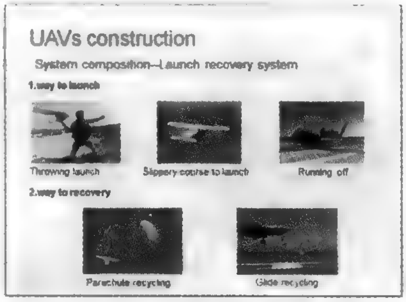
a)



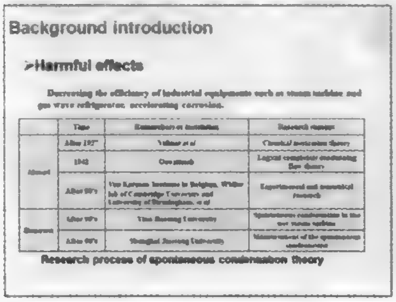
b)



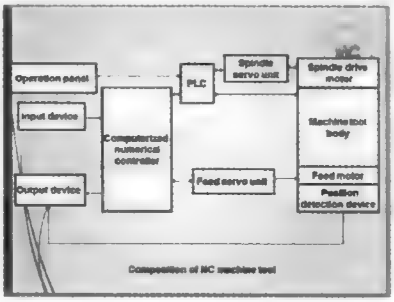
c)



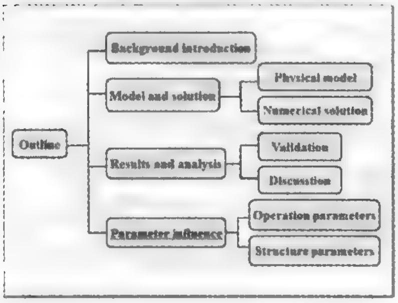
d)



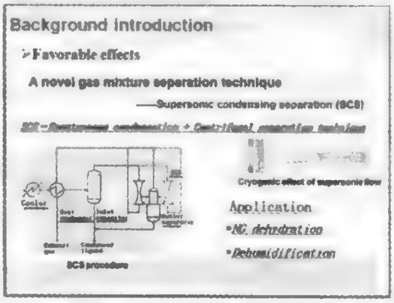
e)



f)



g)



h)

图 13-7　演示文稿制作推荐效果示例

a）标题页　b）大纲页　c）适量文字逐条列出　d）图片排布合理

e）简洁表格　f）流程图的使用　g）框图的使用　h）图文并茂

8. 演示文稿的播放

播放演示文稿时要注意以下几方面：根据演讲时间确定演示文稿的页数，每张演示文稿的展演时间为45～120秒，避免快速掠过；确保演讲的总体时间不超过会议所规定的时间，如果因时间不够需要中止讲演，应快速切换到结论部分并简要阐述；页面的演示要力求顺畅，不同页面的切换要与相关的讲述同步，如需要链接另外的文件（数据库、模拟动画等），一定要简洁、快速；对于讲演中需要重复演示的页面，可采用两页同样的片子以免在演讲中回溯翻页，破坏连贯性。

以外，设置一定的动画效果可以使演示文稿内容根据演讲者需要连续出现，但是动画效果一定要简单，慎用慢速动画和声音。如果采用花样迭出的效果展示和强调内容，如从各个方向闪入、字母和汉字逐个跳出、转圈闪入等，会使观众眼花缭乱、冲淡信息传递效果，甚至降低报告的学术水平。

13.5 讲演前的准备与临场发挥

13.5.1 讲演前的准备

报告人讲演是对讲演人的学术水平和交流能力的全面检验，其重要性不言而喻。成功的讲演取决于演讲人认真、充分的准备，清楚、简洁的演示文稿，以及满怀激情和兴趣的演说。除了做好演示文稿外，在讲演前还需要着手以下准备工作：

1. 不断地演练

报告演示文稿只是为讲演者提供了内容的提纲，讲演者需要对每页演示文稿都非常熟悉，并在脱稿的情况下清晰、流利地讲演每页演示文稿。同时，讲演者还需做好前后演示文稿的衔接工作，用符合逻辑的语言对演示文稿的内容进行连贯的展示；讲演时重点突出，对重点内容反复的、多方面的强调。

尤其当讲演语言不是母语时，讲演者需要花更多的时间进行演练，需要时可以为每一页写好讲稿，然后熟悉到能够流利讲演的程度，这就需要在报告之前做数次演练，可能几十次甚至上百次（学术报告及学术会议主要环节的英语将在第14章系统地介绍）。只有反复地演练，才能为观众提供一场流畅的、精彩的报告，反之如果拿着讲稿去念，尤其讲稿较长时，会使观众感到枯燥、转移注意力，从而降低报告效果。演练的同时还需控制时间，将报告时间严格控制在要求范围之内。在有限的时间内进行有效的展示，做到开场有趣简单、主体部分清楚而不累赘、主次分明、重点突出、结论精炼。

2. 熟悉报告会场

1）熟悉和检查会场设备，确保演示文稿格式与会场的播放设备兼容、影像清晰；调节与麦克风的距离，使音量适当又不产生杂音；激光笔可以自备，以备不时之需。

2）熟悉会场主持人，演讲前应尽可能择机向主持人简要介绍自己，便于主持人会场组织，并缓减自身的紧张。

3）适应会场的氛围，提前到达会场，尽快融入会议的氛围并熟悉和了解其他报告人的讲演内容，尤其是有些可能涉及自己的讲演内容，可以增进学术交流效果。

4）调整注意力和心态，避免过度紧张，但也要有一定的紧张度，有助于集中注意力。

13.5.2 临场发挥

讲演时需要注意以下要点：

1）着装要整齐、正式，妆容简洁，以免给人邋遢或不重视的印象。

2）讲演时可保持静止站立也可自由自动，但是不要分散观众的注意力。眼睛自然地注视听众，避免盯视笔记本、天花板、门窗等单一视点讲演。

3）保持合理的音量、吐字清晰，确保所有听众能听见、听明白；讲演时声音要充满激情、自信，以增强自身报告的可信度。

4）控制语速，并保证口头表达内容与演示文稿内容一致，语气、停顿和手势等肢体语言就是讲演的标点，应配合使用，但不要同时有多个动作，以免给人手忙脚乱的印象。

5）需要强调重点内容时，演讲者应直接在大屏幕上指示，而不是在电脑屏幕上指示；指示内容时，激光笔的光点应相对固定，不宜抖动光点或使用光点画圈，使人眼花缭乱。

6）与观众保持适当的眼神交流，可以帮助集中观众的注意力，尤其当讲演时间较长时，可以根据听众的神态、行为等状况，考虑是否需要改变方式或活跃气氛。注重眼神交流，不要仅盯视特定的一、二位听众，应环顾整个会场、兼顾所有听众。

7）减少口头禅的使用，如“那个”“然后”等。英语讲演时可以适当地采用一些连接词承上启下，如 as you see，once again，for example，all right，so... 等，也可采用 OK...，and...，so...，yes...，furthermore... 等，避免在停顿时用 um uh...，er ah...，ummm... 等语气词的使用。

8）按时结束，以免影响会场的整体安排和影响观众情绪。当时间快到的时候或主持人提醒的时候，如果还没有讲演完，应简洁地强调一下重点内容，尽快翻页到幻灯片的“结论”部分，阐述重要结论结束讲演。

13.6 国际学术交流常用口语表达

本章 13.1 ~ 13.5 节介绍了准备英文学术报告的方法与要点，本节将介绍参加国际学术会议或交流活动时会用到的一般英语表达，可以帮助参会者更好地理解学术会议的安排和其他报告人的演讲内容，更好地展示自己的研究成果并和同行进行有效的交流。

13.6.1 学术会议主持人用语

除了开幕式（opening ceremony）和闭幕式（closing ceremony），国际会议还包含全体会议（plenary session）、分组专题报告（presentation session）和讨论会（discussion）。大会主席往往负责主持开幕式、全体会议及闭幕式，其英语表达具有较强的代表性。因此，本节以大会主席的主持常用程序和表达为例，讲解会议主持人常用英语表达。

1. 开幕式主持用语

欢迎辞：Good afternoon，ladies and gentlemen，may I have your attention please? I'd like to open the morning/afternoon/evening session.

Firstly on behalf of the Sponsors，the School of Nursing，University of Ottawa，I would like to express a very warm welcome to the guests，experts and delegates who have traveled here to partici-

pate in this International Academic Conference. I would like also to express our heartfelt thanks to all the organizations and friends, who have helped and supported us in organizing this conference.

自我介绍：I am ×××, from ×××. It's a great pleasure/privilege for me to chair this session.

大会联合主席介绍：Dr. ×××, who was expected to be the co-chairman for this symposium, could not attend this meeting due to illness. We are honored, however, to have in his place as the co-chairman Dr. ×× on my left. Dr. ×× is the Director for ×××. We are extraordinarily pleased and honored to have him here today to cochair this meeting.

背景、目的介绍：The International Association for ××× was founded in ××× in ×××. It was undertaken ××× congresses in many countries of the world in over ×× years. The purpose of this conference is to share our experiences and knowledge in regard to the theory, new developments, and possible applications of these promising techniques.

会议安排概述：The meeting will tackle the key questions of... The congress will cover a wide range of... The symposium（讨论会）includes a total of ××× papers for presentation at four sessions every half day. Ample time has been allowed for informal discussion. Among the highlights in the program are tutorial lectures on...

期望大会圆满成功：We expect that this conference will offer an opportunity for all participants to form personal ties and above all, to exchange results, ideas, and projects, from which progress will derive. Now I would like to conclude my speech by wishing the conference a complete success.

2. 全体会议主持用语

介绍大会报告主讲人：Our first keynote speaker is ×××, the president of the ×××. She got her Ph. D in ××× at the University of ×××, followed by a series of teaching and research positions at ×××. For the past ×× years, ××× has been a worldwide leader in creating awareness for ××× problem. She has appeared on numerous TV and radio programs here and abroad. Please join me in welcoming our first keynote speaker today—Dr. ××, whose topic is entitled ×××.

报告切换：Thank you, Dr. ×××. Your speech is the absolutely pure gold, very inspiring. We are delighted to be able to share your new specific strategies and techniques. Now, let's welcome our next speaker, Prof. King.

宣布中场休息：We have now come to the end of the first section of this morning. Let's have a 20-minute coffee break. Please come back before 10：00.

宣布全体会议结束：As you are all aware our session has now come to an end and, like you, I am now looking forward to lunch. Now remember, we reassemble at 2：00 in the afternoon, and I thank you for your attendance.

3. 闭幕式用语

致谢：On behalf of all the members of our Organizing Committee, I wish to express our sincere gratitude to all of you who have so actively participated in this congress to make it such a success. First of all, the chairpersons for their efficient ways in which they handled their

sessions. Second, the speakers for their excellent presentations. Third, the delegates for having been an excellent audience and having provided stimulating discussions. Last but not least, I would like to thank the companies for the financial support and cooperation we received in organizing and conducting this conference.

祝贺大会圆满成功：I believe that our conference is a great success.

总结大会成果：It went smoothly as scheduled. In these ××× days the conference has covered so many important and complex problems in the field of ×××, both theoretical and practical. All the presentations were very illuminating and informative, and the heated panel discussions were very stimulating and fruitful.

邀请大家参加下次会议：I am proud to have the privilege to announce that the next International Conference on ××× will be held in ××× in ×××. We will try out best to make the forthcoming gathering another fruitful and pleasant one. We should of course welcome as many scientists as possible. We look forward to seeing you then.

宣布会议闭幕：Ladies and gentlemen, you have my best wishes for your still greater achievements in your career. Now, I declare the conference closed. Let's meet again in ××× in ×××.

13.6.2 学术演讲常用表达

1. 报告前的礼貌用语

感谢主持人介绍：Thank you very much. Professor A. for your gracious introduction.

开场白：Mr. Chairman, Mr. Cochairman, Ladies and Gentlemen, good morning. I am particularly honored to have been invited to speak at this congress.

（临时变更：更改题目）：First of all, I would like to mention that the title of my presentation should be...

（临时变更：更改报告人）：The next speaker, Professor B, regrets that he could not be here and has submitted his paper to me. I am somewhat familiar with his work. I hope I will be able to read this paper. I am not sure whether I will be able to be very confident in answering specific questions, but I will try my best.

2. 讲演流程及例句

提出演讲话题：Today's topic is...

介绍内容要点：I'm going to start with a general overview and then focus on this particular problem from five aspects (the first, the second, a third, another, the final). My presentation will last for about ××× minutes, I will be pleased to answer any questions you may have at the end of the presentation（不允许打断）. / Don't hesitate to interrupt if you have a question.（允许打断）

提出/切换论点：The first (next) point I would like to make about ××× is that...

详述论点：Since this problem is very important to us, I would like to spend some time describing it in greater detail.

概述论点：The subject has recently been reviewed in detail, and I shall sketch in briefly here only describe that...

略过论点（时间限制）：I am sorry that time made it necessary to skip over many details of

×××.

提示将再次提及某论点：I will provide you with some specific information about that in a few minutes.

强调论点：Now I' d like to address myself to the most important aspects of ×××. （一般强调）/It is my opinion that there is no other issue of equal importance to ×××. （一般强调）/ This is "×××", and I repeat "×××" to... （反复强调）/ I believe that my opinions present a viewpoint which may be reasonable and valuable from the standpoint of future investigation on this most important and complex phenomenon. （平行强调）/ It is not because of ××× but because of ×××. （对照强调）/ How serious is the change? How can we solve the problem?（提问式强调）

应对意外打断：Can I come back to that point later?

演讲的总结：Finally, as a summary statement/description, I would like to say that...

3. 问答与讨论

（1）提问例句。

直接提问：May/Could I ask Mr. A to tell us...

间接提问：I'd be grateful/obliged for any comments you may care to make about...

询问原因：Can you give us the reason for your statement?

询问区别：How do you differentiate/distinguish ××× from ×××?

询问关系：Dr. ×××, do you see any relation/connection between ××× and ×××?

询问优缺点：What would you say are its merits and demerits?

询问实验方法：Did you ever try adding ××× instead of ×××?

质疑资料、情报：Do you know (of) any fact by others who have studied this particular question?

质疑看法、观点：You mentioned that... Would you go into this a little more [tell us a little more about this]?

（2）回答例句。

未能听清问题：I am sorry. I couldn't hear what you said. I beg your pardon?

确认问题：I'm not quite sure what your question is [what you mean]. Are you asking me question about...?

对提问者表示感谢：Thank you for (asking) that question. That's a good/big/relevant/important/excellent/interesting/difficult/complicated/hard one.

正面回答：Let me try to answer these questions one by one. In answer to the first question, I would/could/might say that...

无法回答：This kind of experiment hasn't been done yet. This certainly is an important experiment for future consideration.

今后可能解决的问题：The answer to this question is going to need further study.

部分回答：That is one possible explanation, but it is certainly not the only/sole one.

需要协助回答：Fortunately my colleague, Dr. ×××, who is richly experienced in this field, is here. Dr. ×××, would it be fair to ask if you have any comments to make?

回答后回应提问者：I hope this may serve as an answer to Mr. ×××.

(3) 讨论例句。

表示意见、看法：I think/believe/hope/guess/suppose/am afraid/hear so. （肯定）/I am afraid/suppose/believe/guess not. （否定）/I am in complete agreement with you on that point. （赞成）/I respect your opinion, but I think otherwise. （不赞成）/I'd like to present additional information in support of Dr. ×××'s observation. （支持）/Well, as a matter of fact, I would have to say just the opposite. （反对）/（I think）It might/would be a good idea to solve this question. （建议）

陈述意见、观点：I'd like to make a few comments/remarks/observations to clarify some of the points made earlier that I believe might be misunderstood. （一般陈述）/This is an extremely important point that should/must be remembered/recognized/ emphasized should not be forgotten. （强调陈述）

(4) 宣布演讲结束。

礼节性结束用语：My last word again is how honored I am to be invited to talk with you, and I wish you all good luck for the super Congress. Thank you, Professor ×××.

4. 会场技术用语

确认音响效果：Can you (people) hear me?

希望减弱灯光：May/Could/Can I have the lights down [dimmed/out/off].

希望增强灯光：May/Could/Can I [we] have the lights on (now/again/for a moment/ for few minutes), please?

要求改善投影仪聚焦：Could you focus/sharpen it (that) a little bit (more/better), please.

要求调整演示文稿方向：The slide is upside down. Please adjust (correct) it. Thank you.

显示效果不好致歉：I'm sorry the slide is not clear enough, but I hope you can make out the general idea.

Writing Practices

Part 4 写作训练

本部分为本书设置的第三个专业英语实践环节——写作训练，介绍了英语科技论文及应用文体的写作方法。

本部分的学习侧重培养英语写作能力，任课老师可根据学生不同的英语水平因材施教。对于英语基础薄弱的同学，侧重点是写作方法的了解和学习；对于英语基础较扎实的同学，可以在上述基础上进行科技论文写作的实战练习，撰写综述类或设计类英文文章。

Unit 14

英语科技论文写作技巧

科技论文写作几乎是一切科技交流的基础。正如法拉第对科研工作过程的精辟总结——“开拓，研究完成，发表”，科技论文的写作与发表是科学技术研究的重要手段和组成部分，同时还可以促进学术交流和科技合作，有利于科学积累和人才的发现。英语是国际科技交流的通用语言，因此学会阅读和写作英语科技论文，可以更广泛地获得国际先进的科学技术知识，并扩大科研工作者自身科研成果的影响范围。

英语基础较好的本科生或所有研究生在学习专业英语的同时，应当掌握英语科技论文写作的一般方法，并通过写作实践，不断提高自己的写作能力，从而能够得心应手地写出符合要求的论文，即学术价值高、科学性强、文字细节和技术细节表达规范的科技论文，为今后在专业领域从事研究工作和国际学术、技术交流打下良好基础。

14.1 英语科技论文概述

14.1.1 科技论文的概念和特点

1. 概念

科技论文是报道自然科学研究和技术开发创新工作成果的论说文章，它是通过运用概念、判断、推理、证明或反驳等逻辑思维手段，来分析表达自然科学理论和技术开发研究成果的。简单地说，科技论文是对创造性的科研成果进行理论分析和总结的科技写作文体。

2. 特点

科技论文是创新性科学技术研究工作成果的科学论述，是某些理论性、实验性或观测性新知识的科学记录，是某些已知原理应用于实际中取得新进展、新成果的科学总结。科技论文与一般的科技文章相比有共同之处，它们都具有准确、鲜明、生动的特点，但科技论文又有自身的特殊属性。

（1）创新性和独创性　科技论文报道的主要研究成果应是前人所没有的。没有新的观点、见解和结论，就不称其为科技论文。

（2）理论性和学术性　理论性是指一篇科技论文应具有一定的学术价值，它有两个方面的含义：对实验、观察或用其他方式所得到的结果，要从一定的理论高度进行分析和总结，形成一定的科学见解，包括提出并解决一些有科学价值的问题；对自己提出的科学见解或问题，要用事实和理论进行符合逻辑的论证与分析或说明，总之要将实践上升为理论。科技论文的写作过程，本身就是作者在认识上的深化和在实践基础上进行科学抽象的过程。

（3）科学性和准确性　科学性就是正确地说明研究对象的特殊矛盾，尊重事实和科学。科学性包括论点正确、论据充分、论证严密、推理符合逻辑、数据可靠、处理合理、计算精确、实验可重复、结论客观等。准确性说明对客观事物即研究对象的运动规律和性质表述的接近程度，包括概念、定义、判断、分析和结论准确，对自身研究成果确切、恰当的估计，对他人研究成果（尤其是在做比较时）的评价实事求是，切忌片面性和说过头话。

（4）规范性和可读性　撰写科技论文是为了交流、传播、储存新的科技信息，因此科技论文必须按一定格式写作，并且必须具有良好的可读性。在文字表达上，要求语言准确、简明、通顺，条理清楚，层次分明，论述严谨。在技术表达方面，包括名词术语、数字、符号的使用，图表的设计，计量单位的使用，文献的著录等都应符合规范化要求。

14.1.2　科技论文的分类

科技论文可按几种不同的方法进行分类，可如按其学科分类，可分为物理学论文、化学论文、医学论文、数学论文等。本节从两个主要角度对科技论文进行分类，并说明各类论文的概念及写作要求。

1. 就发挥的作用来看科技论文可分为 3 类

（1）学术性论文　该类型论文是指提供给学术性期刊发表或向学术会议提交的论文，它以报道学术研究成果为主要内容。学术性论文反映了该学科领域新的、前沿的科学成果和发展动向。这类论文应具有新的观点、新的分析方法和新的数据或结论，具有相当的科学性。

（2）技术性论文　该类论文是指工程技术人员为报道工程技术研究成果而提交的论文，研究成果主要是应用已有的理论来解决设计、技术、工艺、设备、材料等具体技术问题而取得的。技术性论文对技术进步和提高生产力起着直接的推动作用。这类论文应具有技术的先进性、实用性和科学性。

（3）学位论文　该类论文是指学位申请者提交的论文。学士论文应反映出作者具有专门的知识和技能，具有从事科技研究或担负专门技术工作的初步能力。论文一般只涉及不太复杂的课题，论述的范围较窄，深度也较浅。硕士论文是在导师指导下完成的，但必须具有一定程度的创新性，强调作者的独立思考作用。博士论文可以是 1 篇论文，也可以是相互关联的若干篇的总和。博士论文应反映出作者具有坚实、广博的基础理论知识和系统、深入的专门知识，具有独立从事科学技术研究工作的能力，应反映出该科学技术领域最前沿的独创性成果。

学位论文要经过考核和答辩，因此无论是论述还是文献综述，还是介绍实验装置和实验方法都要比较详尽；而学术性和技术性论文则是写给同专业的人员看的，要力求简洁。除此之外，学位论文与学术性论文和技术性论文之间并无其他严格的区别。

2. 按研究的方式和论述的内容，科技论文又可分为 6 类

（1）实（试）验研究报告　这类论文写作重点应放在“研究”上，追求的是可靠的理论依据，先进的实（试）验设计方案，先进、适用的测试手段，合理、准确的数据处理及科学、严密的分析与论证。

（2）理论分析型　这类论文主要是对新的设想、原理、模型、机构、材料、工艺、样品等进行理论分析，对过去的理论分析加以完善、补充或修正。其论证分析要严谨，数学运

算要正确，资料数据要可靠，结论除了要准确而外，一般还须经实（试）验验证。

（3）理论推导型　这类论文主要是对提出的新的假说通过数学推导和逻辑推理，从而得到新的理论，包括定理、定律和法则。其写作要求是数学推导要科学、准确，逻辑推理要严密，并准确地使用定义和概念，力求得到无懈可击的结论。

（4）设计计算型　这类论文介绍解决某些工程、技术和管理问题的计算机程序设计，某些系统、工程方案、机构、产品的优化设计，某些产品（包括整机、部件或零件）或物质（材料、原料等）的设计或调、配制等。写作要求是相对要“新”，数学模型的建立和参数的选择要合理，编制的程序要能正常运行，计算结果要合理、准确；设计的产品或调、配制的物质要经试验证实或经生产、使用考核。

（5）专题论述型　这类论文是指对某些事业（产业）、某一领域、某一学科、某项工作发表议论（包括立论和驳论），通过分析论证，对它们的发展战略决策、发展方向和道路，以及方针政策等提出新的独到的见解。

（6）综合论述型　这类论文应是在作者博览群书的基础上，综合介绍、分析、评述该学科（专业）领域国内外的研究新成果、发展新趋势，并表明作者自己的观点，做出发展的科学预测，提出比较中肯的建设性意见和建议。其基本要求是资料新而全，作者立足点高、眼光远，问题综合恰当、分析在理，意见和建议应较为中肯。

14.2 篇前部分的写作

一般来说，科技论文的组成部分依次为：题名、作者署名、摘要、关键词、引言、正文、结论（和建议）、致谢、参考文献和附录。其中，题名、作者署名、摘要和关键词属于篇前部分，示例如图 14-1 所示；引言、正文和结论属于主体部分；致谢、参考文献和附录属于篇后部分。

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Numerical investigation of the heat and mass transfer in a vertical tube evaporator with the three-zone analysis

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ABSTRACT

A numerical study for the flow, heat and mass transfer characteristics near the inflow region of the vertical evaporating tube with the films flowing down on both the inside and outside tube walls has been carried out. Condensation occurs along the outside wall and evaporation at the free surface of the inside film. The transport equations for momentum and energy are parabolized by the boundary-layer approximation and solved by using the marching technique. In this kind of numerical approach, the accurately predicting the early stage is really important because a small error at the previous step can produce the amplified big error at the next step. To accurately predict the flow at the inflow region of the vertical evaporating tube, the calculation domain of two film flow regions and tube wall is solved simultaneously. The interesting heat transfer characteristics revealed through this three-zone simulation, such as the evaporation delay and the temperature inflection at the very near inflow region are found and discussed along the discrepancy between the inner film inlet temperature and the saturation temperature. The case that the inner film comes in with the saturation temperature shows a good performance. The velocity and temperature fields as well as the amounts of the condensed and evaporated mass in both inner and outer films are predicted for the various conditions.

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图 14-1　篇前部分组成示例

（来源：International Journal of Heat and Mass Transfer，2009，52：2599-2606）

14.2.1 论文题名

1. 概念

题名，又称题目、篇名等，是论文的总纲，是能反映论文最重要的特定内容的最恰当、最简明的词语的逻辑组合。

2. 类型

1）名词词组（最常见）：Mechanical properties of parts fabricated with inkjet 3D printing through efficient experimental design （通过有效实验设计改进的3D喷墨打印制造零件的力学性能）

2）主副题名：Creation of curved surface by lathe turning—development of CAM system using original tool layout （曲面的车削加工——使用原有机床刀具布置的计算机辅助加工系统的发展）

3）系列题名：Dynamic simulation and control of an integrated gasifier/reformer system. Part II: Discrete and model predictive（汽化器/重整装置集成系统的动力学模拟和控制，第二部分：离散和模型预测）

4）陈述性题名（最少见）：The p21 Cdk-interacting protein Cip1 is a potent inhibitor of G1 cyclin-dependent kinases （p21 Cdk作用蛋白（又称Cip1）是G1细胞周期依赖性蛋白激酶的强抑制剂）

5）疑问句题名：Can African countries efficiently build their economies on renewable energy?（非洲国家能否建立有效的可再生能源经济结构?）

3. 撰写标题的ABC三原则

（1）准确（Accuracy） 题名应能准确地表达论文的中心内容，恰如其分地反映研究的范围和达到的深度，不能使用笼统的、泛指性很强的词语和华而不实的辞藻。常见的毛病有如下几种：

1）题名反映的面大，而实际内容包括的面窄。比较下面三个题名，其中第①题名太过宽泛，甚至都无法定焦研究领域；②将研究范围适当地进行了缩小，但是研究对象仍不明确；③最为恰当，既反映了研究范围，又确定了研究对象，而文字表达也与正文研究内容对应。

①“Effects of external mechanical loading”（外部力学载荷的影响）

②“Effects of external mechanical loading on stress generation”（外部力学载荷对应力产生的影响）

③“Effects of external mechanical loading on stress generation during lithiation in Li-ion battery electrodes”（外部力学载荷对锂离子电池电极的锂化反应过程中应力产生的影响）

2）标题一般化，不足以反映文章内容的特点。比较下面两个题名，其中第①题名没有特色，读者从题名只能看出来是一种新型的表面等离子共振传感器，而无法知道新在何处，无法区别该装置与其他表面等离子共振传感器；②体现了创新点，即将光纤对接技术应用到表面等离子共振传感器中产生的新型装置，该题目直接体现了论文的特色，并与文章内容相符。

①“A novel surface plasmon resonance sensor”（一种新型表面等离子共振传感器）

②“A novel surface plasmon resonance sensor based on fiber butt-joint technology”（一种基

于光纤对接技术的新型表面等离子共振传感器）

（2）简洁（Brevity） 题名应简明。标准规定，题名“一般不宜超过20个字”。在保证能准确反映“最主要的特定内容”的前提下，题名字数越少越好，英文文题不超过10~12个实词。为减少题名的字数，可参考以下方法：

1）删去多余的词语。例如：尽量少用或不用“Study on...” “Investigation on...” “Observation on...” “Thoughts on...” “Regarding...” 等词。

2）避免将同义词或近义词连用。

3）英文题名中的冠词有简化的趋势，凡可用可不用的冠词均可不用。

4）用加副题名的办法来减少主题名的字数，但采用副题名还可以起到其他作用。①题名语意未尽，用副题名补充说明论文的特定内容，如“Robotics camps, clubs, and competitions: Results from a US robotics project”（机器人阵营、俱乐部和比赛：美国机器人项目的研究结果）；②一系列研究工作用几篇论文报道，或者是分阶段的研究结果，各用不同的副题名区别其特定内容，如“Dynamic simulation and control of an integrated gasifier/reformer system. Part I: Agile case design and control”（汽化器/重整装置集成系统的动力学模拟和控制，第一部分：灵巧装置设计和控制），“Dynamic simulation and control of an integrated gasifier/reformer system. Part II: Discrete and model predictive”（汽化器/重整装置集成系统的动力学模拟和控制，第二部分：离散和模型预测）；其他有必要用副题名作为引申或说明的情况。

（3）清楚（Clarity） 清晰地反映文章的具体内容和特色，力求简洁有效、重点突出。

1）尽可能将表达核心内容的主题词放在题名开头。

2）慎重使用缩略语，所用缩略语应是行业共用共知的缩略语。

3）避免使用化学式、上下角标、特殊符号（数字符号、希腊字母等）、公式。

4）恰当使用介词，如标题“Formulation *of* equations *of* vertical motion *of* finite element form for vehicle-bridge interaction system”中多次使用“of”造成形式重复和语意不明，可改为“Finite element based formulations for vehicle-bridge interaction system considering vertical motion”（车桥相互作用系统有限元形式的竖向运动方程），语意更明确。

5）题名所用词语必须有助于选定关键词和编制题录、索引等二次文献，以便为检索提供特定的实用信息。

14.2.2 署名、工作单位及通讯地址

1. 署名的意义

1）署名作为拥有著作权的声明。《中华人民共和国著作权法》中规定：“著作权属于作者”；著作权包括“署名权，即表明作者身份，在作品上署名的权利”。在发表的论文中署名，是国家赋予作者的一种权利，当然受到国家法律的保护。

2）署名表示文责自负的承诺。所谓文责自负，就是论文一经发表，署名者即应对论文负责。如果论文中存在剽窃、抄袭的内容，或者政治上、科学上或技术上存在错误，那么署名者就应完全负责，署名即表示作者愿意承担这些责任。

3）署名便于读者同作者联系。署名也是为了建立作者与读者的联系。读者阅读文章后，若需要同作者商榷，或者要询问、质疑或请教，以及寻求帮助，可以直接与作者联系。

2. 署名对象

署名者只限于那些参与选定研究课题和制定研究方案、直接参加全部或主要部分研究工作并做出主要贡献，以及参加论文撰写并能对内容负责，同时对论文具有答辩能力的人员；仅参加部分工作的合作者、按研究计划分工负责具体小项的工作者、某一项测试任务的承担者，以及接受委托进行分析检验和观察的辅助人员等，均不应署名，但署名者可以将他们作为参加工作的人员一一列入“致谢”段，或注于篇首页脚注。

个人的研究成果，个人署名；集体的研究成果，集体署名（一般应署作者姓名，不宜只署课题组名称）。集体署名时，按对研究工作贡献的大小排列名次。论文的执笔人或主要撰写者应该是第一作者，与第一作者贡献相同的作者可署名共同第一作者或通讯作者。署名时避免“搭车”署名，不能遗漏应该署名的作者，不可擅自将知名人士署为作者之一以提高论文声誉和影响。

3. 署名的位置与格式

通常，学术性期刊中将署名置于题名下方，并采用如下格式：作者姓名（作者工作单位名称及地址）。

1）姓名表达方式。国外期刊一般会尊重作者对自己姓名的表达方式，但大多倾向于大写字母只限用于姓和名的首字母。采用缩写表达时，名可以采用首字母大写表示，姓一般不缩写，如中文名字“李明”，采用的缩写表达为“Li M.”或“M. Li”。科研工作者在发表文章时应尽量采用相对固定的英文姓名的表达形式，以减少在文献检索和论文引用中被他人误解的可能性。

2）工作单位及地址。尽可能地给出详细的通讯地址，一般的格式为“系（学院），大学（机构），城市，邮编，国家”。如果论文出版时作者调到一个新的地址，新地址应以“Present address”（现地址）的形式在脚注中给出。如果第一作者不是通讯作者，则作者应按期刊的相关规定表达，并提前告诉编辑，期刊多以星号（*）、脚注或致谢的形式标注通讯作者或联系人。

14.2.3 摘要

1. 定义及作用

摘要是对“论文的内容不加注释和评论的简短陈述”。一篇完整的论文都要求撰写随文摘要，摘要不能脱离文章而单独印刷发行。摘要高度概括了正文叙述的内容，突出正文的重点，是正文实质性内容的介绍，其作用有二：

1）让读者尽快了解论文的主要内容，以补充题名的不足。科技文献数量大，读者不可能一拿到文章就通读。是否需要通读某篇论文，从题名上进行判断后，主要的是根据摘要来决定，所以，摘要担负着吸引读者和介绍文章主要内容的任务。

2）为科技情报人员和计算机检索提供方便。论文发表后，文摘杂志对摘要可以不做修改或稍做修改而直接利用，从而可避免由他人编写摘要可能产生的误解、欠缺和错误，这就为科技文献的检索和利用提供了极大的方便。

2. 分类

（1）指示型摘要 指示型摘要即介绍型摘要，也称陈述型摘要。它只简要地介绍论文的论题，或者概括地表述研究的目的，仅使读者对论文的主要内容有一概括的了解。指示型

摘要一般不介绍方法、结果、结论的具体内容，不包含任何数据。综述类的论文较多采用指示型摘要。

指示型摘要示例：

Title：A survey of Sensor Fusion Methods in Wearable Robotics

Abstract：Modern wearable robots are not yet intelligent enough to fully satisfy the demands of end-users, as they lack the sensor fusion algorithms needed to provide optimal assistance and react quickly to perturbations or changes in user intentions. Sensor fusion applications such as intention detection have been emphasized as a major challenge for both robotic orthoses and prostheses. In order to better examine the strengths and shortcomings of the field, this paper presents a review of existing sensor fusion methods for wearable robots, both stationary ones such as rehabilitation exoskeletons and portable ones such as active prostheses and full-body exoskeletons. Fusion methods are first presented as applied to individual sensing modalities (primarily electromyography, electroencephalography and mechanical sensors), and then four approaches to combining multiple modalities are presented. The strengths and weaknesses of the different methods are compared, and recommendations are made for future sensor fusion research.

（引自：Robotics and Autonomous Systems, Volume 73, November 2015, 155 - 170）

（2）报道型摘要　报道型摘要即资料型摘要或信息型摘要。它用来报道论文所反映的作者的主要研究成果，向读者提供论文中全部创新内容和尽可能多的定量或定性的信息。尤其适用于试验研究和专题研究类论文，多为学术性期刊所采用。报道型摘要一般由4部分组成：

1）目的（What I want to do?）：即本文的目的或要解决的问题。一般来说，一篇好的英文摘要，一开头就应该把作者本文的目的或要解决的主要问题非常明确地交代清楚。

2）方法（How I did it?）：即论文的主要工作过程及所采用的技术手段或方法，还包括众多的边界条件，使用的主要设备及仪器仪表等。对新的技术手段则应清楚地描述其基本原理、应用范围及所达到的精度、误差等。

3）结果（What results did I get?）：结果应力求简明而富有信息性，可以是所获得的实验数据、实验结果及关系式，也可以是理论性成果，还可以是所关注的相关联系及观察到的主要现象。

4）结论（What conclusions can I draw?）：即阐明成果蕴含的意义，特别阐述这种意义是怎样与研究目的相联系的。

为了论述方便，有些摘要中结果和结论也紧密结合在一起写。结果和结论代表着文章的主要成就和贡献，论文有没有价值，值不值得读者阅读，主要取决于所获得的结果和所得出的结论。因此，在写结果和结论部分时，一般都要尽量结合实验结果或仿真结果的图、表、曲线等来加以说明，使结论部分言之有物，有根有据。

报道型摘要示例：

Title：Energy and Exergy Performance Analysis of a Marine Rotary Desiccant Air-Conditioning System Based on Orthogonal Experiment

Abstract：（目的）A novel marine rotary desiccant A/C (air-conditioning) system was developed and studied to improve energy utilization efficiency of ship A/C. （方法）The orthogonal experiment was first carried out to investigate the influence of various parameters of the marine rotary

desiccant A/C system. During the orthogonal experiment the analysis of variance was used to exclude interference from the secondary influencing factor on system performance. The significant influencing factors of system were studied in great detail using the first and second laws of thermodynamics to find optimal setting parameters for best system performance. （结果）It is suggested from the analysis results that as regeneration temperature increases, the COPth (thermal coefficient of performance) and exergy efficiency of system (ηe) decrease by 46.9% and 38.8% respectively. They decrease in proportion to the increase of the temperature. ηe reaches its maximum value of about 23.5% when the inlet humidity ratio of process air is 22g/kg. Besides, the exergy loss of system concentrates on the regeneration air heater, the desiccant wheel and the regeneration air leaving the desiccant wheel, which account for 68.4% ~81% of the total exergy loss. （结论）It can be concluded that applying the marine rotary desiccant A/C in high-temperature and high-humidity marine environment is advantageous.

（引自：Energy, Volume 77, 1 December 2014, Pages 953 –962）

（3）报道-指示型摘要　报道-指示型摘要是介于上述两种摘要之间的摘要类型，以报道型摘要的形式表述论文中价值最高的那部分内容，其余部分则以指示型摘要形式表达。

报道-指示型摘要示例：

Title：Experiments and Simulation of a Solar-Assisted Household Biogas System

Abstract：Almost all of finished household biogas plants in China incorporated medium-temperature fermentation and no auxiliary heating were integrated. Accordingly the production efficiency was quite poor due to lack of reasonable thermal support. Meanwhile solar-collector became more and more popular accompanied with decreasing cost resulting from mass production. （指示型）A solar-assisted biogas system was put forward and experimentally investigated in this paper. The initiative was to combine popularly-available house biogas plant with solar-collector at a reasonable cost, therefore to maintain year-round operation of biogas plant and to produce enough amount of biogas in winter for daily use. （报道型）The recorded data in a pilot project revealed that additional electricity consumed accounted to only 7.2% of biogas produced, suggesting an economically feasible approach.

（引自：Energy Procedia, Volume 61, 2014, Pages 1760 – 1763）

3. 撰写要求

（1）用第三人称　作为一种可供阅读和检索的独立使用的文体，摘要只能用第三人称而不用其他人称来写。

（2）简短精练，明确具体　要达到这个要求，可以参考以下方法：

1）尽量写短句：英文科技文章写作时，经常使用复合句，有时一个子句套一个子句，整个一句话很长。在摘要中尽量写短句子，如果碰到长句子也尽量拆成几个短句子。例如下面一句话长达49个词：

What is really required therefore is a safe, reliable and inexpensive device, which can be inserted between the transmission line and the consuming apparatus, to convert the high voltage and low current of the economical transmission line into the low voltage and high current required by the consuming apparatus.

可将其拆为两句话：

A safe, reliable and inexpensive device is really required between the transmission line and the consuming apparatus. It can convert the high voltage and low current of the economical transmission of the economical transmission line into the low voltage and high current required by the consuming apparatus.

2）取消一些不必要的词句。摘要中的第一句话不要与题名重复，因为题名往往比较长，重复题名会无形中增加摘要的长度且没有必要。还有一些不必要的词汇，如 in this paper..., It is reported that..., Extensive investigations show that..., The author discusses..., This paper concerned with... 等都可以取消，减小长度。

3）减少或取消不必要的背景信息。摘要只限表示新消息、新内容，应减少或取消对过去研究情况的描述，减少或取消不必要的背景信息。摘要也不应该包括作者未来的计划，如“有关×××方面的研究有待进一步开展”等。

4）对物理量单位及通用词适当简化。如用3km 代表 three kilometers，用5s 代替 five seconds，用 U.S.（美国）代表 the United States 等。同时，描述物理量时尽量避免重复单元，采用简化措施。如在摘要中：不采用 at a high temperature of 1250℃，应采用 at 1250℃简要说明。

（3）格式要规范　尽可能用规范术语，不用非共知共用的符号和术语。不得简单地重复题名中已有的信息，并切忌罗列段落标题来代替摘要。除了实在无变通办法可用以外，一般不出现插图、表格，以及参考文献序号，一般不用数学公式和化学结构式。摘要段置于作者之后，关键词之前。

（4）选词要准确，词能达意，不要引起读者误解。如 safety 与 security 两词是同义词，都可以做安全讲，但其含义是有所不同的。safety 是“安全，平安”的意思，可指自身安全、使用产品的安全等，如安全保险措施（safety precautions）、（汽车）安全带（safety belt）、安全阀（safety valve）、安全岛（safety island）、安全运行（safety operation）等。而 security 则是“安全，保护，保障”的意思，如养老金的保障、（防盗）安全措施、保安措施均用 security 一词，又如国家的防卫、保安部队、保安车（如押送金钱的）等。文字表达上应符合“语言通顺，结构严谨，标点符号准确”的要求。摘要中的语言应当符合现代汉语的语法规则、修辞规则和逻辑规则，不能出现语病。

（5）时态要符合要求　英文摘要多采用一般现在时和过去时，采用一般现在时明确研究的目的、描述研究的内容、得出结果与结论等；采用一般过去时描述作者过去某一时刻（时段）的发现、某一研究（观察、调查、实验、治疗等）过程等。如“Calculated water velocities are close to the experimental values with deviation of ±5%.”表示结果，用一般现在时；“The fatigue tests of notched specimens under random loads were carried out.”表示过去某一时段的实验过程，用过去时。

4. 常用词汇和短语（表 14-1）

表 14-1　摘要常用词汇和短语

（1）作者观点和文章内容					
英　文	中　文	英　文	中　文	英　文	中　文
deal with	论及，涉及	describe	阐述	explain	解释

（续）

(1) 作者观点和文章内容					
英　文	中　文	英　文	中　文	英　文	中　文
illustrate	说明	introduce	引入，介绍	present	给出
report	给出，报道	indicate	表明	point out	指出
(2) 文章研究课题					
英　文	中　文	英　文	中　文	英　文	中　文
analyse	分析	consider	认为，考虑	develop	推导，开发
discuss	讨论	investigate	研究，调查	state	叙述，　阐述
study	研究	explain	解释	derive	推导
(3) 文章涉及范围					
consist of	由……组成	contain	包含	cover	包含，涉及
include	包含，包括	be composed of	包含	encompass	包含，围绕
(4) 综述与概括					
outline	概要叙述	review	评述，回顾	summary	概述，总结
(5) 强调重点					
There is a focus on...	重视，集中	Attention is paid to...	重视	Attention is concentrated on...	重点是
The emphasis is on...	重点是	be focused on	集中在……	Attention is attracted on...	重点是
(6) 文章目的					
aim	目的	objective	目标，对象	purpose	目的
seek for	寻求，追求	goal	目标，目的	target	目标，目的
(7) 成果获取和研究结果					
achieve	达到，实现	objective	目标，对象	purpose	目的
seek for	寻求，追求	construct	绘制，构建	design	设计
establish	建立	record	记录	give	给出
realize	实现	improve	改进，提高	provide	提供
obtain	得到，获得	produce	生产	reduce	缩短，降低
solve	解决	increase	增加	enlarge	扩大
demonstrate	示范，证明	exhibit	展示，展出	find out	发现
observe	观察	show	表明	enhance	强化，加强
(8) 研究方法					
calculate	计算	determine	确定，测得	simulate	模拟，仿真
estimate	估计，估算	measure	测量	compare	比较
agree with	一致，符合	assess	评审，评价	evaluate	估算，评估
experiment	实验	test	测试	apply	应用
(9) 论证与依据					
be based on	基于……，根据……	on the basis of	基于……，根据……	take as reference	做参考

14.2.4 关键词

关键词作为论文的一个组成部分，列于摘要段之后。关键词是为了满足文献标引或检索工作的需要而从论文中选取出的词或词组。

关键词包括主题词和自由词两个部分。每篇论文中应专门列出 3～8 个关键词，它们应能反映论文的主题内容。其中主题词应尽可能多一些，它们可以从综合性主题词表（如《汉语主题词表》）和专业性主题词表［如 NASA（美国国家航空和宇航局）词表、INIS（国际核信息系统）词表、TEST 词表、MeSH 词表（美国《医学主题词表》）等］中选取。那些确能反映论文的主题内容但现行的主题词表还来不及收入的词或词组可以作为自由词列出，以补充关键词个数的不足或更好地表达论文的主题内容。

不要使用过于宽泛的词做关键词（如机械工程，材料科学等），以免失去检索的作用；避免使用自定的缩略语、缩写字作为关键词，除非是科学界公认的专有缩写字（如 CAD）。

14.3 主体部分的写作

14.3.1 引言

论文的引言又称绪论。写引言的目的是向读者交代本研究的来龙去脉，其作用在于唤起读者的注意，使读者对论文先有一个总体的了解。英文科技论文的写作中，引言很重要，审稿人可以从作者的引言内容中了解作者对该研究方向的熟悉程度，从而影响他对论文价值的判断。

1. 内容构成

1）综述研究背景，概述本项工作的研究或观察的理论基础，给出简明的理论或研究背景，一定要列举重要的相关文献。

2）指出存在问题，便于引出自己的研究目的。

3）阐述研究目的，尤其说明有别于他人的想法，即创新之处。

4）概述文章内容，以及预期的研究结果、作用和意义。

2. 写作要求

（1）言简意赅，突出重点　共知的、前人文献中已有的不必细写。主要写好研究的理由、目的、方法和预期结果，意思要明确，语言要简练。

（2）开门见山，不绕圈子　背景介绍时直奔主题，有针对性地指出研究意义。

（3）逻辑性强，思路清晰　与中文科技论文相比，英文科技论文的引言篇幅比较长，内容比较系统充实，往往相当于某一研究方向的短篇综述。作者需要理清思路，把握逻辑，按照背景（意义）介绍、前人相关研究成果综述、存在问题提出、本文解决问题及创新之处、文章主要内容简介的顺序，完成引言写作。

（4）如实评述，防止吹嘘自己和贬低别人　叙述前人工作的欠缺以强调自己研究的创新时，应慎重且留有余地，避免使用“首次提出”“重大发现”等词语。

（5）正确引用文献，符合引用要求　应引用“最相关”的文献以指引读者，切忌刻意

回避引用最重要的相关文献；避免不恰当地大量引用作者本人的文献。

（6）在引言中要正确运用时态：

1）叙述有关现象或普遍事实时，句子的主要动词多使用现在时，如“little is known about...”或“little literature is available on...”。

2）描述特定研究领域中最近的某种趋势，或者强调表示某些“最近”发生的事件对现在的影响时，常采用现在完成时，如“few studies have been done on...”或“little attention has been devoted to...”。

3）在阐述作者本人研究目的的句子中应有类似“This paper, The experiment reported here”等词，以表示所涉及的内容是作者的工作，而不是指其他学者过去的研究。例如：“In summary, previous methods are all extremely inefficient. Hence a new approach is developed to process the data more efficiently.”容易使读者产生误解，其中的第二句应修改为：“In this paper, a new approach will be developed to process the data more efficiently.”

14.3.2 正文

正文即论证部分，是论文的核心部分。论文的论点、论据和论证都在这里阐述，因此它要占主要篇幅。因为论文作者的研究工作涉及的学科、选题、研究对象和研究方法、工作进程、结果表达方式等差异很大，所以对正文要写的内容不能做统一规定；但是，总的思路和结构安排应当符合“提出论点，通过论据（事实和（或）数据）来对论点加以论证”这一共同的要求。

1. 立意与谋篇

立意与谋篇是一般写作，也是科技论文写作的中心环节。正文是论文的核心部分，其立意与谋篇就是显得特别重要。立意就是把论文的主题思想在正文部分确立起来；谋篇就是要安排好正文的结构，选择好正文的材料（论据），以便充分而有效地表达论文的主题（论证）。

（1）确立主题　主题，即作者总的意图或基本观点的体现，对论文的价值起主导和决定作用。对科技论文主题的基本要求是：

1）主题新颖，就是要研究、解决、创立和提出前人没有研究和解决的问题。选题时必须广泛查阅文献资料，了解与本课题有关的前人的工作；研究时应从新的角度去探索；写作时应认真分析研究实验、观察、测试、计算及调查、统计结果，得出新的见解和观点。

2）主题深刻，就是要抓住问题的本质，揭示事物的主要矛盾，总结出事物存在、运动、变化和发展的客观规律。要使主题深刻，就不能停留在简单地描述现象，堆砌材料，和盘托出实验或观测、统计数据的阶段上，而应透过现象抓住事物的本质，在分析材料、整理实验或观察结果的基础上提出能反映客观规律的见解，将实践知识上升为理论，得出有价值的结论。

3）主题集中，就是一篇论文只有一个中心。要使主题集中，就不能面面俱到，凡与本文主题无关或关系不大的内容不应涉及，否则就会使问题繁杂，脉络不清，主题淡化。

4）主题鲜明，就是论文的中心思想地位突出，除了在论文的题名、摘要、引言、结论部分明确地点出主题外，在正文部分更要注意突出主题。

（2）选择论据（材料）　论据即材料，是为了表现主题而收集到的各种事实、数据和观

点等。按来源来分，材料可分为直接材料、间接材料、发展材料。

选择材料时应遵循以下原则。

1）必要而充分。必要即必不可少，缺此不能表现主题。写作时应紧紧抓住这类材料，与主题无关的材料，则不论来得多么不容易也不要采用。充分即量要足够，没有一定的数量，难以论证清楚问题，即所谓“证据不足”。有足够的量，才能从中选出足够的必要材料。

2）真实而准确。真实即不虚假，材料来自客观实际，即来自社会调查、生产实践和科学实验，而不是虚拟或编造的。准确即完全符合实际。写作时要尽量用直接材料；对间接材料要分析和核对，引用时要在全面理解的基础上合理取舍，避免断章取义，更不能歪曲原意；形成发展材料时，要保持原有材料的客观性。

3）典型而新颖。典型即材料能反映事物的本质特征。这样的材料能使道理具体化，描述形象化，有极强的说服力。要获得典型的材料，调查和研究工作必须深入，否则难以捕获事物的本质；应善于从众多、繁杂的材料中取其具有代表性的内容，而将一般性的材料不吝舍去。新颖即新鲜，不陈旧。要使材料新颖，关键是要做开拓性工作，不断获得创新性成果。

（3）确定论证方法　论证是指用论据证明论点的推理过程，其作用是说服读者相信作者论题的正确性，即“以理服人”。论证是科技论文的主要表达方式，也是在正文部分所要采用的基本写作手段。论证是由论点、论据和论证方式等3个环节组成的。论点来源于主题，论据来源于材料，前已述及，这里仅归纳出常用的论证方式，以供参考。

1）举例。即“摆事实”，用具体事实（包括数据）来证明论点。思维形式是归纳推理。

2）事理引申。以人们已知的道理为论据来证明作者的观点。其思维形式是演绎推理。

3）反证、归谬。从先假定某一论点是正确的，然后以此为前提，导出一个显然是荒谬的结论，从而证明假定的论点是错的。其思维形式是演绎反驳推理。

4）类比。将甲类事物与乙类事物做对比，以乙类事物的正确与否来证明甲类事物的正确与否。其思维形式是类比推理。

5）对比。将截然相反的两种情况进行比较，形成鲜明的对照，从而证实一方面的存在或正确。其思维形式也是类比推理。

6）因果互证。通过事理分析，揭示论点与论据之间的因果关系，以此证明论点的正确性。其思维形式是归纳推理。

2. 结构与内容

（1）理论分析　理论分析也称基本原理，包括论证的理论依据、对所做的假设及其合理性的阐述，对分析方法的说明。内容可包括假说、前提条件、分析的对象、适用的理论、分析的方法、计算的过程等。写作时应注意区别哪些是已知的（前人已有的），哪些是作者首次提出来的，哪些是经过作者改进的，须交代清楚。

（2）实验材料和方法　实验材料的表述需对材料的来源、性质和数量，以及材料的选取和处理等事项进行详述。方法的表述应描述实验所用的仪器、设备，以及实验条件和测试方法等。内容可包括实验对象，实验目的，实验材料的名称、来源、性质、数量、选取方法和处理方法，使用的仪器、设备（包括型号、名称、量测范围和精度等），实验及测定的方法和过程，出现的问题和采取的措施等。写作时应注意以下要求：

1）材料和方法的阐述必须具体、真实、清楚、准确。应遵循的原则是给出足够的细节信息以便让同行能够重复实验，因为科学技术研究成果必须接受检验。如果方法新颖且不曾发表过，应提供所有必需的细节，必要时可用示意图、方框图或照片图等配合表述。如果所采用的方法已经公开报道过，应当引用相关的文献，注明出处。

2）力求语法正确、描述准确。由于材料和方法部分通常需要描述很多的内容，因此通常需要采用较为简洁的语言，但同时要保证语法正确。

3）时态与语态的运用：

① 若描述的内容为不受时间影响的事实，采用一般现在时，如描述实验设备时可用一般现在时；

② 若描述的内容为特定、过去的行为或事件，则采用过去时，如表述实验步骤或过程时用过去时；

③ 由于读者关注的是文中所采用的材料和使用的方法，所以一般采用被动语态描述；如果涉及表达作者的观点或看法，也可采用主动语态。

（3）结果与讨论　结果与讨论是论文的关键部分，也是论文的价值所在。内容包括给出结果，并对结果进行定量或定性的分析、讨论。

1）以绘图和列表等手段整理实验结果。给出实验结果时要对数据进行整理，并采用合适的表达形式，如插图或表格等，但要避免使用文字、图、表重复同一数据。表格和图形应具有“自明性”，即不需要文字辅助说明就可以表达相应含义。

① 表格：很方便地列举大量精确数据或资料，一般采用三线表，如图 14-2 所示。

Table 1
Geometries of the test micro-tubes.

Number	Inner diameter/mm	Outer diameter/mm	Length/mm
1	0.317	0.608	70
2	0.571	0.793	70
3	0.727	1.032	70
4	0.869	1.221	70

Table 2
Experimental conditions

Parameter	Values
Vapour pressure(p)/kPa	31.16,47.38,84.53
Vapour velocity(U)/m·s^{-1}	2,4,6

图 14-2　三线表示例

（来源：Applied Thermal Engineering，2015，88：185-191）

② 图形：直观、有效地表达复杂数据，尤其是不同组数据间的比较、关联、趋势等。数据图中横、纵坐标表示的物理量、单位、范围和间隔要表达清晰；合理使用图例，各条曲线能清楚区分，不产生混淆。数据图示例如图 14-3 所示。

③ 图表题名（图题与表头）：准确而清楚地表达出数据或资料的含义，切忌简单地描述数据。如图 14-2 和图 14-3 所示，表头一般置于表的上方，图题一般置于图的下方。

2）通过数理统计和误差分析说明结果的可靠性、再现性和普遍性，进行实验结果与理论计算结果的比较，说明结果的适用对象和范围，分析不符合预见的现象和数据，检验理论分析的正确性等。压缩或删除那些众所周知的一般性道理的叙述，省略那些不必要的中间步骤或推导过程，突出精华部分。

3）对结果进行讨论，解释所取得的研究结果，说明结果的意义，指出自己的结果与前人研究结果或观点的异同，讨论尚未定论之处和相反的结果，提出研究的方向和问题。最主要的是突出新发现、新发明，说明研究结果的必然性或偶然性。

4）时态要求：

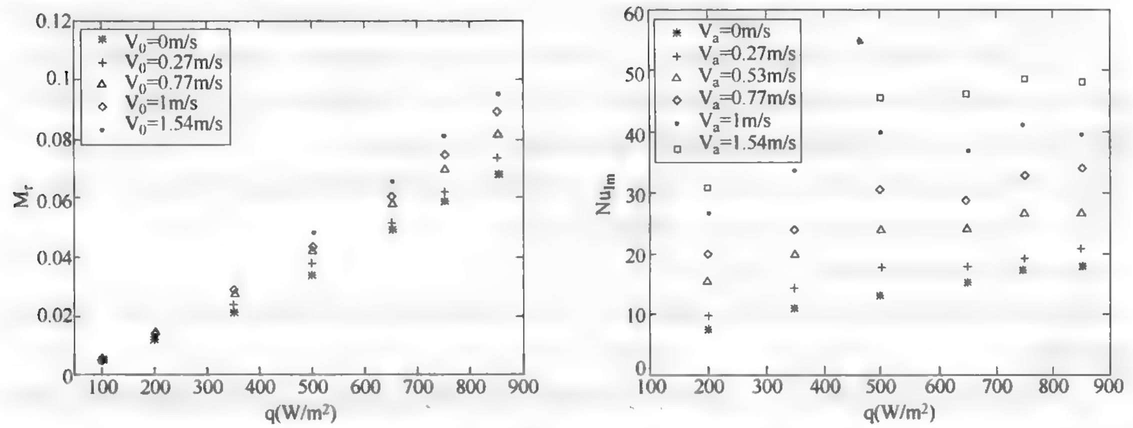

Fig 15 Mass fraction of evaporated water with respect to the heat flux for different values of the velocity of blown air(m_{in}=7.22×10^{-4}kg·s^{-1};$T_{in,eq}$=21=22℃;T_0=26=27℃; Φ_0=67=69%)

Fig 17 Mean latent Nusselt number with respect to the heat flux for differnt values of the velocity of blown air(m_{in}=7.22×10^{-4}kg·s^{-1};$T_{in,eq}$=21=22℃;T_0=26=27℃; Φ_0=67=69%)

图 14-3　数据图示例

（来源：International Journal of Thermal Sciences，2011，50：942-953）

① 指出结果在哪些图表中列出，常用一般现在时；

② 叙述或总结研究结果的内容为关于过去的事实，通常采用过去时；

③ 对研究结果进行说明或由其得出一般性推论时，多用现在时；

④ 不同结果之间或实验数据与理论模型之间进行比较时，多采用一般现在时。

14.3.4　结论

作者在文章的最后要单独用一节对全文进行总结，其主要内容是对研究的主要发现和成果进行概括总结，让读者对全文的重点有一个深刻的印象，这就是结论。结论又称结束语、结语，它是在理论分析和实验验证的基础上，通过严密的逻辑推理而得出的富有创造性、指导性、经验性的结果描述。

结论与引言相呼应，同摘要一样，其作用是便于读者阅读和为二次文献作者提供依据。有的文章也在本部分提出当前研究的不足之处，对研究的前景和后续工作进行展望。应注意的是，撰写结论时不应涉及前文不曾指出的新事实，也不能在结论中重复论文中其他章节中的句子，或者叙述其他不重要或与自己研究没有密切联系的内容，故意把结论拉长。

1. 内容

结论不是研究结果的简单重复，而是对研究结果更深入一步的认识，是从正文部分的全部内容出发，并涉及引言的部分内容，经过判断、归纳、推理等过程，将研究结果升华成新的总观点。其内容要点如下：

1）本研究的结果说明了什么问题，得出了什么规律性的东西，解决了什么理论或实际问题。

2）对前人有关本问题的看法做了哪些检验，哪些与本研究结果一致，哪些不一致，作者做了哪些修正、补充、发展或否定。

3）本研究的不足之处或遗留问题。

对于某一篇论文的结论，上述要点 1）是必需的，而要点 2）和 3）视论文的具体内容

和需要而定。如果不可能导出结论，也可以没有结论，而进行必要的讨论。

2. 格式与要求

如果结论段的内容较多，可以分条来写，并给以编号，每条成一段，每段可以是几句话或一句话；如果结论段内容较少，可以不分条写，成为一个自然段。

结论里应包括必要的数据，但主要是用文字表达，一般不再用插图和表格。

撰写的结论应达到如下要求：

1）概括准确，措辞严谨。结论是论文最终的、总体的总结，对论文创新内容的概括应当准确、完整，不要漏掉任何一条有价值的结论，但也不能凭空杜撰。措辞要严谨，语句要像法律条文那样，不能模棱两可，含糊其词。肯定和否定要明确，一般不用“大概”“也许”“可能是”这类词语。

2）明确具体，简短精练。结论段有相对的独立性，专业读者和情报人员可以只看摘要和（或）结论就能大致了解论文反映的成果和成果的价值，所以结论段应提供明确、具体的定性和定量的信息。对要点要具体表述，不能用抽象和笼统的语言。可读性要强，如一般不单用量符号，而宜用量名称，比如，说“λ 与 Re 呈反比关系”不如说“沿程损失系数与雷诺数成反比”易读。语言要锤炼，删去可有可无的词语。

3）不做自我评价。论文的真正价值是通过具体“结论”来体现的，是由读者来评说的，不宜在文中进行主观评价。

14.4 篇尾部分的写作

14.4.1 致谢

现代科学技术研究往往不是一个人能单独完成的，而需要他人的合作与帮助，因此当研究成果以论文形式发表时，作者应当对他人的劳动给以充分肯定，并对他们表示感谢。对于不够署名条件，但对研究成果确有贡献者，可以“致谢”的形式列出。致谢的对象通常包括：

1）协助研究的实验人员。

2）为研究提供方便（仪器、测试等）的机构或人员。

3）提出过指导性意见的人员。

4）资金资助项目或类别，如“The financial supports by the National Natural Science Foundation of China（项目编号）are gratefully acknowledged.”表示对国家自然基金项目资助的致谢。

“致谢”段可以列出标题并贯以序号，如“6　致谢”放在如“5　结论”段之后，也可不列标题，空1行置于“结论”段之后，具体格式可参考所投刊物的要求。

14.4.2 参考文献

参考文献是为撰写或编辑论著而引用的有关图书资料。在科技论文中，凡是引用前人（包括作者自己过去）已发表的文献中的观点、数据和材料等，都要对它们在文中出现的地方予以标明，并在文末列出参考文献表。

1. 著录作用

对于一篇完整的论文，参考文献著录是不可缺少的。归纳起来，参考文献著录的作用主要体现在以下5个方面：

1）著录参考文献可以反映论文作者的科学态度和论文具有真实、广泛的科学依据，也反映出该论文的起点和深度。

2）著录参考文献能方便地把论文作者的成果与前人的成果区别开来。论文在阐述和论证过程中免不了要引用前人的成果，包括观点、方法、数据和其他资料，若对引用部分加以标注，则他人的成果将表示得十分清楚。这表明了对他人劳动的尊重，而且也免除了抄袭、剽窃他人成果的嫌疑。

3）著录参考文献能起索引作用。读者通过著录的参考文献，可方便地检索和查找有关图书资料，以对该论文中的引文有更详尽的了解。

4）著录参考文献有利于节省论文篇幅。论文中需要表述的某些内容，凡已有文献所载者不必详述，只在相应之处注明文献出处即可。这不仅精炼了语言，节省了篇幅，而且避免了一般性表述和资料堆积，使论文容易达到篇幅短、内容精的要求。

5）著录参考文献有助于科技情报人员进行情报研究和文献计量学研究。

2. 著录原则

1）必须是亲自阅读过。

2）优先引用：最新发表、特定期刊（领域内的权威期刊），或领域内知名专家的论文。

3）避免过多的作者自引。

4）遵循拟投稿期刊的体例要求。

5）确保文献各著录项（作者姓名、论文题目、期刊或专著名等）正确无误。

3. 体例类型

参考文献常用的体例类型有两种：著者-出版年体系（name-year system，N-Y），如图14-4所示；顺序编码体系（citiation-order system 或 citiation-sequence system，C-S），如图14-5所示。

Becker (1989) developed a single-effect alcohol-salt (CH_3OH–$LiBr/ZnBr_2$) absorption heat pump using a plate-and-fin type compact heat exchanger (trapezium offset strip fins made of Inconel 600 brazed on 700 mm × 240 mm × 1 mm stainless steel plates) as the absorber. He mentioned that the theoretical heat transfer coefficients on the film side were 2.5–6 times larger than the measured values (0.15–0.25 kW/m² K for $4 < Re_f < 24$ and $75 < Pr < 120$) and suspected incomplete wetting of the absorber surface as one of the reasons.

Flamensbeck et al. (1998) developed a double-effect water-hydroxides (H_2O–$NaOH/KOH$) absorption chiller employing plate heat exchangers for the condenser (four commercial nickel-brazed plate heat exchangers connected in parallel) and the high-pressure condenser/mid-pressure generator (a plate-and-fin heat exchanger similar to that of Becker (1989)).

正文引用示例

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Bankoff, S.G., 1971. Minimum thickness of a draining liquid film. Int. J. Heat Mass Transfer 14, 2143–2146.

Becker, H., 1989. Compact heat and mass exchangers of the plate fin type in thermal sorption systems, Dissertation, TU Delft.

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Estiot, E., Natzer, S., Behr, C., Eichel, P., Kren, C., Schweigler, C., 2006. Wärmetauscherentwicklung für kompakte Wasser/LiBr-Absorptionskälteanlagen. In: Proc. of Deutsche Kälte-Klima-Tagung, Dresden.

参考文献列表示例

图14-4 著者-出版年体系参考文献示例

（来源：International Journal of Heat and Mass Transfer，2010，53：1146－1155）

Since the work of Uchida et al.'s work [5], which provided the first practical correlation for degradation of condensation from NC gas from experiments with steam–gas condensation on vertical wall, there is substantial amount of experimental and modeling work done on condensation of steam inside a vertical tube in the presence of NC gas [6–23]. Most of these work relate to the through flow mode operation of the PCCS and were conducted with secondary heat removal through forced convention cooling except Kim and No [18] who used pool boiling, but in a large rectangular tank, and the experiments did not involve the presence of NC gas. Table 1 gives the summary of all experimental work on PCCS related studies. Oh and Revankar [24–27] performed series of experiments with single vertical tube condenser that simulated all three modes of PCCS operation: through flow, cyclic venting, and complete condensation mode and used the realistic secondary heat transfer condition – pool boiling heat transfer. A boundary layer model and heat and mass transfer analogy model were developed based on the methodology presented by Colburn and Hougen [28] to simulate PCCS condensation. Here in this work a new multi-tube test facility was designed and constructed to extend Oh and Revankar's research [24] as well as to investigate the tube bundle effect on PCCS heat removal capabilities [29]. The present work focuses on experiments and analysis of the through flow condensation mode in a multi-tube condenser.

正文引用示例

References

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[6] H.K. Al-Diwany, J.W. Rose, Free convection film condensation of steam in presence of non-condensing gases, Int. J. Heat Mass Transfer 16 (1973) 1359–1369.
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[9] M. Siddique, The effects of noncondensable gases on steam condensation under forced convection conditions, Ph.D. Thesis, Massachusetts Institute of Technology, Cambridge, MA, 1992.
[10] S.Z. Kuhn, Investigation of heat transfer from condensing steam–gas mixtures and turbulent films flowing downward inside a vertical tube, Ph.D. Thesis, Department of Nuclear Engineering, University of California, Berkeley, CA, 1995.

参考文献列表示例

图 14-5 顺序编码体系参考文献示例

（来源：International Journal of Refrigeration，2008，32：138－149）

Unit 15

其他英文应用文体写作

15.1 信函

英文信函可以分为两类：非正式信函和正式信函。非正式信函又称私人信函（personal letters），正式信函一般是商务信函（business letters），给陌生人或重要的人写信也用正式信函。以下分别介绍英文信函的信封和信笺的书写格式及其写作要点。

1. 信封的格式

英文信函的信封由三个主要部分构成，其格式与中文信函不同：发信人的姓名、地址或单位名称放在信封的左上角，收信人的姓名、地址或单位名称则通常居中，邮票置于信封的右上角。英文信函的信封范例如图 15-1 所示。

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Stamp

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图 15-1　英文信函的信封范例

书写英文信函的信封时应注意以下两点：

1）地址顺序由小到大，先写姓名或单位名称，再写门牌号和具体地点，有邮政编码的不要忘记加上，寄往国外的信函要写上国名。如果地址较长，可以分成几行，一般按并列式（block style）排列，如图 15-1 所示。在英式用法中，允许采用斜列式（indented style）。

2）为表示礼貌，收信人的姓名前通常冠以 Mr.，Mrs.，Miss，Ms. 等称谓。若知道收信人的头衔，则应该在其姓名前加上头衔。若不知道收信人的姓名，可以写上 To Whom It May Concern（致有关人士），或者直接写上公司或机构的名称。

2. 信笺的格式

（1）组成部分及写作要求　英文信笺的一般组成部分如图 15-2 所示，主要包括以下六部分。

1）信头（Heading），写发信人的地址和日期（右上角）。

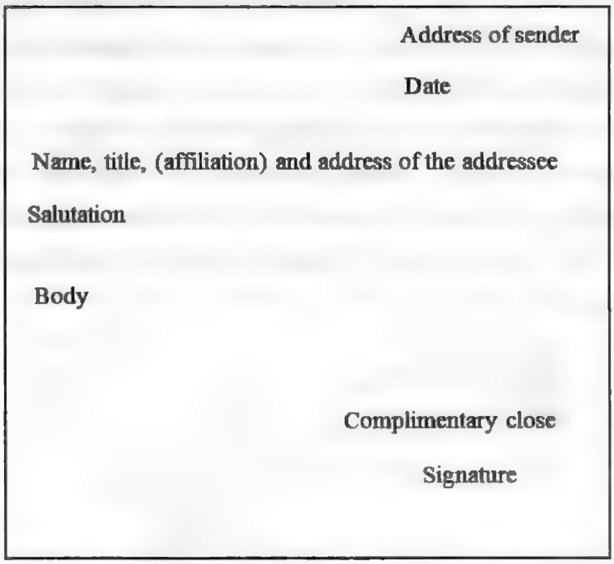

图 15-2　英文信笺的一般组成部分

2）信内姓名地址（Inside address），写收信人的姓名、称呼、单位和地址（左上角），其位置要低于发信人的地址和发信日期的位置。在英式用法中，地址的每一行末尾加逗号，最后一行加句号，美式用法不用加。

中英文信函的发信日期有不同的写法。中文信函的日期写在署名之后，英文信函的日期写在信笺的开始。在美式用法中，发信日期的书写次序是月、日、年，英式用法的书写次序是月、日、年或日、月、年。

3）称呼（Salutation），写对收信人的尊称，信笺中对收信人的称呼与信封上的大致相似，但通常都以 Dear 开头，称呼的末尾用逗号，如 “Dear Mr. . . . ,” “Dear Madam Helen,” “Dear Miss. . . ,” “Dear John,” “Dear Prof. Smith,” 等。称呼直接写在收信人地址的正下方，中间空一至二行。

4）正文（Body），即信件内的主要内容。

5）信尾客套语（Complimentary close），结束正文后，在署名前要添上结尾客套语，客套语的末尾用逗号。客套语置于信的右（或左）下角，一般有 “Sincerely,” “Sincerely yours,” “Yours sincerely,” “Friendly yours,” “Truly yours,” “Yours truly,” “Cordially yours,” “Yours cordially,” 等。

6）信尾签名（Signature），亲笔签上发信人姓名。如果是用打字机或计算机写的信，署名时应先亲笔签名，然后在手写体签名的下面再打上姓名。如果发信人为女性，与收信人又不相识，可以在打印的姓名左边或右边用括号中注上 Miss，Mrs. 或 Ms. 。署名之后还可添上本人的职称或头衔。

（2）书写款式　英文书信的款式一般有两种：齐头式（Block Style）和折中式（Semi-Block Style）。齐头式常在商贸、官方以及一些正式的信件中使用，以显示信件内容的严肃性、真实性、可靠性。而折中式信笺则显得比较随便，主要用于家人、朋友、私人之间来往的信件。如果两人之间不是第一次通信，相互比较了解，则可以省略信内的双方地址。

1）齐头式。用齐头式写信，其正文与称呼之间空一至二行。每段的第一句不需要空格，但段与段之间需要空一至二行。齐头式信件的信尾客套话和签名可以有两种款式。第一种写在左下方，这是最常用也是最正式的。另外也可以写在右下方，这种形式则表示写信人与收信人之间的关系比较熟悉随便。齐头式信笺示例如图 15-3 所示。

2）折中式。用折中式书写信件，其正文与称呼之间空一至二行。第一段第一句的第一个单词必须在 Dear 后称呼的正下方。以后每段开头都要与第一段第一个字对齐。信尾的客套话和签名都写在右下方。朋友之间写信一般都使用折中式，而且称呼与正文之间一般不空行。折中式信笺示例如图 15-4 所示。

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Dear Prof. John Smith,

This is a request for admittance to your department as a visiting scholar. I hope it will be possible for me to take some courses and also do some research works in your University. Our government will provide me with all traveling and living expenses.

Enclosed please find my application and two recommendation letters, which I hope you will find satisfactory. Thank you for your kind consideration.

I am looking for your reply.

Sincerely yours,
Li Ming

图 15-3　齐头式信笺示例

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September 18, 2015

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Dear Prof. John Smith,

　　This is a request for admittance to your department as a visiting scholar. I hope it will be possible for me to take some courses and also do some research works in your University. Our government will provide me with all traveling and living expenses.

　　Enclosed please find my application and two recommendation letters, which I hope you will find satisfactory. Thank you for your kind consideration.

　　I am looking for your reply.

Sincerely yours,
Li Ming

图 15-4　折中式信笺示例

15.2　便笺和通知

最简单的应用文体莫过于便笺（Notes）和通知（Notice），它们共同的特征是简短，只有一个标题，除此之外，还应具备表达准确、条理清晰、醒目易读等特点。

1. 便笺

便笺有四个基本要素：日期、收件人、便笺内容和留言人。如果只有收件人才有可能见到便笺的话，则收件人写在便笺的顶端，否则将便笺折叠起来，收件人写在便笺的外面。便笺范例如下：

Fri. Dec. 18

Prof. Wang,

I'd like to discuss with you the content of my *Thesis Proposal*. Could you appoint a time and give

me a message? Thank you.

Li Ming

2. 通知

通知是上级对下级、组织对成员布置工作、传达情况或告诉公众某种事情等时使用的一种应用文体，通常分为口头通知和书面通知两种。

（1）口头通知　口头通知是面对面地把信息传达给对方。这种通知开头应有称呼语，正式场合用“Ladies and gentlemen”（女士们、先生们），有时也可以用“Boys and girls”或“Comrades and friends”（同志们、朋友们）等。开头还常有提醒听众注意的开场白，如“Attention, please.”“May I have your attention, please?”“I have an announcement to make.”等。结尾常说“That's all. Thank you.”“Thank you (for listening).”等，以示礼貌。口头通知无须说明发布通知的日期和发布通知的人或单位。

（2）书面通知　书面通知的格式有两种，一种是以布告形式贴出，把事情通知有关人员，如学生、观众等，通常不用称呼；另一种是以书信的形式，发给有关人员，这种通知的写法有点类似于书信的写法，只要写明通知的具体内容即可。通知是传达将要做的事，因此写通知多用一般现在时和将来时态。通知表达信息应简明扼要、措辞得当、时间及时，其内容包括所通知活动的时间、地点和内容，以及其他信息，如学术报告会的演讲者介绍、活动的组织者等。

范例一　布告形式的通知：通常此类通知上方正中写 Notice 或 NOTICE（通知），发出通知的单位的具体名称可放在正文前，也可放在正文后、右下角处，发出通知的日期写在左下角处。例如：

NOTICE

All teachers are requested to meet in the college conference room on Saturday, December 18, at 4: 30 PM to discuss curriculum arrangements for next semester.

December 18, 2015

Mechanical and Electrical Engineering School

范例二　书信形式的通知：

Dear author,

Submission of PEEM2016 is open now! The topics include Power System Management, Power Generation—Conventional and Renewable, Energy Analysis and Management, Sustainable Emerging and Renewable Energy Technologies as well as other related topics.

And all the PEEM2016 accepted papers will be published by DEStech Publications. DEStech Publications will submit all the papers to be indexed in EI Compendex, Thomson Reuters Web of Science CPCI-S (ISTP indexing) and CNKI Scholar for worldwide online citation.

Paper Submission due: December 13, 2015.

Please send your Paper (s) and Submission Form to E-mail: peem2016@163.com. Regular papers are allowed to 5 pages. Extra pages (exceed 5 pages) will incur additional charges.

Thank you for your support in advance and look forward to your reply.

Best Regards
PEEM2016 Committees
(Source: http://www.peem2016.org/)

15.3 简历

15.3.1 格式和组成

简历（Resume 或 Curriculum vitae）是求职或求学的第一块敲门砖，直接会关系到应试者给面试官的第一印象和是否能得到面试机会，因此每个求职者或求学者都应该精心准备，制作一份清楚详细、重点突出的简历。在应聘外贸公司，以及一些外资或合资的大公司时，招聘公司都会提出需要一份英文简历。英文简历主要由个人简况（personal data）、学历（education）和经历（experience）三个部分组成，还可以根据不同需要增加一些项目，如求职目标（job objective）、外语技能（foreign language skills）、兴趣爱好（hobbies and interests）、奖励和荣誉（honors and awards）等。

英文简历一般并没有特别固定的形式，求职者可以根据个人的需求和情况来选择不同的侧重点，加以设计，形成自己的个人简历。在通常情况下，英文简历可根据侧重点分为三种格式：

1. 以学历为主的简历（Basic Resume）

这种形式的英文简历比较适用于应届毕业生，由于相关工作经历较少，所以把重点放在学业上，突出专业知识、专业能力、语言能力及学习过程中的其他收获和成绩，如社团工作等。

范例一　以学历为主的简历

Resume

Personal Information

Name:	Gender:
Data of Birth:	Major:
Graduate school:	Degree:
E-mail:	Phone:
Address:	

Objective

To obtain a challenging position as a mechanical engineer, especially in mechatronic equipment design and maintenance.

Education

2013.09 – now　Dept of Mechanical and Electrical Engineering, ×××University, Master Degree

2009.09 – 2013.07　Dept of Mechanical and Electrical Engineering, ×××n University, Bachelor degree

Academic Main Courses

Theoretical Mechanics, Material Mechanics, Mechanical Drawing, Mechanical Design, Mechanism & Machinery, Technology of Mechanical Manufacture, Engineering Materials, Automation of Mechanical Manufacture System, Computer Control in Mechanical Manufacture, Mechatronics, Robot, Shape Design of Mechanical Products, Digit Control Technique, Principle & Interface Technique of Micro-Computer.

Language Abilities

Have a good command of both spoken and written English. Past CET-6; TOEFL: 623; GRE: 2213.

Computer Abilities

Skilled in use of Win XP / Office 07/AutoCAD/Pro-Engineering

Community Activities

2014.09 – now **Graduate Student Council Vice Minister of Information**

☆ Participate in the South China University of volunteers' activity called Caring for Autistic Children, the volunteer who is responsible for the entire process of photography.

2010.09 – 2013.4 **Vice President, Deputy Minister of Self-Discipline, Counselor Assistant, Living Members of the Class**

☆ Three years as living members of the class, and actively cooperate with the squad leader to organize class outdoor barbecue, rooftop tours and other activities, learning stress relief, harm-onious relationship between students;

☆ Deputy Chairman, organized the college students to participate in athletic meets, pre-training organization capable to make college achieved its best results.

Scholarships and Awards

2010.10 Excellent Cadre of Youth League Award of ××× University

2011.05 Excellent Students Cadre of ××× University

2015.11 National Scholarship of China

Research Projects

2013.09 – now School-enterprise cooperation projects: Equipment design and optimization for water purification in natural rubber manufacturing process.

Intership Experience

2015.07 – 2015.09 **Hainan Purifying Water Treatment Co. Ltd, Supervising Engineer Assistant.**

☆ Assist supervising engineer check the safety of the water treatment process conditions;

☆ Assist the Engineer notice issued security management.

Self Evaluation

☆ Have sunny disposition

☆ Methodical and conscientious

☆ Mature and professional

☆ Capable to adjust to different circumstances

☆ Good team player, able to work under pressure

☆ Responsible and easy-going.

2. 以经历为主的简历（Chronological Resume）

这种简历适用于从事相关领域工作多年、工作经验较丰富的求职者，工作经历是求职亮点，因此也是简历表达的侧重点，常常放在学历之前。求职者需要对工作经历中的内容、结果、成就等详尽描述，按时间由近至远的顺序列出。当工作经历较多时，需要重点突出，将重要业绩，尤其是与目标岗位相关的经历详尽描述，次要经历可以一笔带过，无关经历可以省略，但应保证经历的连贯性。

范例二　以经历为主的简历

Name

Mobile：+86××××××××××× Email：×××@×××.com

Address：×××

Job Objectives

To obtain a challenging position as a mechanical engineer, especially in mechatronic equipment design and maintenance.

Work Experiences

××× 2013 – Present **Company Name (Location)**

Role:

☆ What was my responsibility

☆ What I achieved

☆ Awards (Recognitions) I received during this position

☆ Anything worth mentioning

××× 2011 – ××× 2013 **Company Name (Location)**

Role:

☆ What was my responsibility

☆ What I achieved

☆ Awards (Recognitions) I received during this position

☆ Anything worth mentioning

Educations

University | Degree Title | Results

☆ Subjects I studied

☆ Anything worth mentioning

Awards (or Skills)

☆ Any awards/scholarship (year)?

☆ Any certificates?

☆ Languages you speak?

☆ Computer skill you master?

☆ Any other technical skill related to the job?

Reference

☆ Your Linked In URL

☆ Professors/former manager's phone number and e-mail

3. 以职能为主的简历（Functional Resume）

与第二种形式相比，突出职能的简历虽然也同样侧重工作经历，但是按不同的工作性质来划分工作经历，时间上并不一定连贯，而仅仅是将不同的工作阶段中相同的职务和业务归纳在一起。

15.3.2 写作要点

简历是求职者常用的一个工具。在毕业生的求职过程中，简历往往是获得面试机会的重要工具。下面谈谈简历的写作要点。

1. 简历要有针对性

如果你试图制作一份万能简历，投递给所有的单位，那么这份简历的最终归宿可能就是HR的废纸框，因为每个单位、每个职位都有不同的要求，招聘者希望在你的简历中找到“为什么你适合他们招聘的职位?”，以及“你将如何去适应这个职位?”的答案。因此简历最重要的是要有针对性，这个针对性有两层含义：一是简历要针对所应聘的公司和职位；二是简历要针对自己，写出自己适合该职位的能力和业绩。

应届生写简历前需将自己在大学的学习、社会工作和生活仔细回想一遍，写出有亮点的事情。如成绩优秀，获得过奖学金或者获得过什么竞赛奖励等；参加过学生会工作、学生社团工作，到哪些单位实习过，组织过什么活动，取得过什么业绩等；在大学里做过什么有意义的事等。然后找出与众不同的地方，根据所应聘的岗位和公司进行一定的筛选和修改。如果应聘技术型的工作，则简历要重点突出专业成绩、实践能力、团队精神（社团活动）等。如果应聘销售类的工作，则简历要重点突出沟通能力、人际交往能力和不服输的精神，应体现社会活动业绩，曾经做过的兼职，以及工作业绩。

2. 简历要内容完整

一份简历至少要包括以下几个方面的内容：

1）应聘的岗位或求职希望。

2）基本信息：姓名、性别、联系方式（邮寄地址和邮编、联系电话、电子邮箱）。

3）教育背景：最高学历、毕业院校、专业。

4）与应聘岗位需求素质有关的表现、经历和业绩等，要重点突出，条理清楚。

5）可以附上有关证明材料的复印件，如获得奖学金、优秀干部、实习鉴定、专业资格证书和发表过的论文的复印件。

3. 简历要重点突出

简历中需要重点突出的部分就是应聘单位所关注的内容，这些内容的阐述是否详尽、是否合理直接关系到是否能得到面试机会。

（1）成绩和嘉奖　以取得的突出业绩来证明自己的加盟会给应聘单位带来莫大的收益，运用数字、百分比或时间等量化手段可以强化业绩效果。嘉奖是对学习和工作中表现出色的肯定，表述时最好能突出嘉奖与所求职务的相关性。成绩与嘉奖都是求职者工作能力的客观、量化表述，其可信度、说服性更强。

（2）能力　针对招聘岗位要求对各方面的能力加以归纳和汇总，扬长避短，真实客观。用词应简单明确、观点鲜明。

（3）工作经历　应当包括所有的工作历史，无论是有偿的还是无偿的，全职的还是兼

职的。在保证真实性的前提下，尽量扩充与丰富工作经历，但用词必须简练。采用倒序的格式描述，并保持每份纪录的独立性。工作经历也可以和业绩、成果融合到一起写，因为业绩、成果是在工作过程中取得的。

（4）技能　列出所有与求职有关的技能。尤其对于专业性较强的岗位，技能水平直接决定能否胜任岗位要求。

4. 简历的形式要整洁、美观

简历一般不需要太长，关键要突出重点，一般要打印出来，字体为五号或小四号。简历有没有封面没有关系，一般岗位的简历不需要太花哨，关键是要有内容、不空洞。对于一些特殊的岗位，如设计类、公关类、策划类的岗位，简历形式可以别出心裁，与众不同。

5. 简历要注重细节

避免出现语法、拼写或格式错误，因为这些错误能够直接反映出你的态度以及对应聘单位、职位的重视程度。描述工作经历时也要注意细节，例如：

A 曾担任过学校学生会副主席；

B 曾担任过学校学生会副主席，带队参加了挑战杯华南赛区决赛，并取得一等奖。

以上两者都表述了同样的经历，但是充满重要细节的 B 却能更吸引招聘者的眼球。

15.4 说明书

说明书，是以应用文体的方式对某事或物来进行相对的详细描述，方便人们认识和了解某事或物。说明书要实事求是，有一说一、有二说二，不可为达到某种目的而夸大产品作用和性能。说明书要全面地说明事物，不仅介绍其优点，同时还要清楚地说明应注意的事项和可能产生的问题。

一般来讲，按所要说明的事物来分，说明书可以分为以下几种：

1. 产品说明书

产品说明书主要是指关于日常生产、生活产品的说明书。它主要是对某一产品的所有情况的介绍，诸如其组成材料、性能、存贮方式、注意事项、主要用途等的介绍。这类说明书可以是生产消费品的，如电视机；也可以是生活消费品的，如食品、药品等。

2. 使用说明书

使用说明书是向人们介绍具体的关于某产品的使用方法和步骤的说明书。

3. 安装说明书

安装说明书主要介绍如何将一堆分散的产品零件安装成一个可以使用的完整的产品。为便于运输，许多产品都是拆开分装的，因此用户在购买到产品之后，需要将散装部件合理地安装在一起，在产品的说明书中就需要有一个具体翔实的安装说明书。

4. 戏剧演出说明书

这是一种比较散文化的说明书，它的主要目的在于介绍戏剧、影视的主要故事情节，同时也是为了向观众推荐该影剧。大型的演出活动，对于演职员的介绍、节目的介绍等也是为了吸引更多的观众而采用的一种宣传式的说明文字。

产品说明书、使用说明书、安装说明书专业技术性较强，一般采用说明性文字，并可根据情况需要，使用图片、图表等多样的形式，以期达到最好的说明效果。为便于说明书的阅

读和理解，帮助用户快速安装和正确使用产品，本书提供了一些英文说明书中常见的词汇和短语，见表 15-1。

表 15-1 英文说明书中常见的词汇和短语

英 文	中 文	英 文	中 文	英 文	中 文
user's manual	用户手册	feature	特点	construction	构造
electric system	电气系统	cooling system	冷却系统	test run	试运转
first commissioning	试车	maintenance	维护，维修	dimensions	尺寸
measurement	尺码	lubrication	润滑	inspection	检验
location	安装位置	fix screw	固定螺钉	specifications	规格
rated load	额定负载	rated capacity	额定容量	nominal speed	额定转速
nominal horsepower	额定马力	Gross/Gr. Wt.	毛重	Net Wt.	净重
fragile	易碎	cutting capacity	切削容量	humidity	湿度
oiling period	加油间隔期	work cycle	工作周期	recyclable	可回收利用的
Handle with care	小心装卸	Heave here	从此提起	haul	此处起吊
Keep in cool place	置于阴凉处	Not to be tipped	勿倾倒	stuffing	填充料
cleaning	清洗	guarantee	保修书	operational instructions	操作说明书
major components and functions	主要部件及功能	assembles and controls	各部件及其操作机构	group designation	总类名称
operating flow chart	操作流程图	fine adjustment	微调	coarse adjustment	粗调
direction for use	使用方法	wear-life	抗磨损寿命	high voltage cautions	小心高电压
transportation	搬运，运输	instruction for erection	安装规程	power requirements	电源条件
service condition	工作条件	system diagram	系统示意图	wiring/circuit diagram	线路图
operating voltage	工作电压	factory services	工厂检修服务	specific wearability	磨损率
precautions /cautions	注意事项	measuring range	量程	data book	数据表
Don't cast	勿掷	standard accessories	标准附件	accessories supplied	备用附件
safety factor	安全系数	tested error free	经检验无质量问题	ground/GND terminal	接地端子
earth lead	地线	inflammable	易燃物，防火	Keep dry	保持干燥
Keep upright	勿倒置	To be protected from cold/heat	避免遇冷/热	Use rollers	移动时使用滚子

15.5 合同与协议书

在英语中，合同一般称为 Contract，协议一般称为 Agreement。

1999 年中国《合同法》第二条对 contract 定义为："A contact in this Law refers to an agreement establishing, modifying and terminating the civil rights and obligations between subjects of equal footing, that is, between natural persons, legal persons or other organizations."。根据这一定义，合同是平等主体之间设立的确定民事权利和义务的协议。

关于"Agreement"，"Black's Law Dictionary" 中给出两个定义。一个是："A concord of understanding and intention between two or more parties with respect to the effect upon their relative rights and duties, of certain past or future facts or performance"。根据这一定义，协议即双方或多方就某些过去或将来事实的相关权利、义务或相关权利、义务的履行而达成的一致理解和愿望。另一个是："The consent of two or more persons concurring respecting the transmission of some property, right or benefits, with the view of contacting an obligation, a mutual obligation." 根据这一定义，协议即两个或多个当事人，为了约定单方责任或相互责任，就财产权利、利益的转移取得的一致同意。

合同和协议书都是两方或多方就某项事宜达成合作或约定的文件，它们的概念虽然接近，但使用范围不同，不能互换使用。合同是协议的重要组成部分，所有合同一定是协议，而协议不见得都是合同。可以说具备合同成立要求的具有强制执行力的协议才是合同。相比较而言，合同的内容通常都有详细而严格的规范，往往具有很强的法律约束力，多涉及经济领域和人事聘任等；而协议则主要涉及人员培训、技术合作等领域。

1. 英文合同用词特点

合同英语的用词极其考究，具有特定性。要求选词专业化（professional）、正式（formal）、准确（accurate）。具体体现在下列方面：

（1）may，shall，must，may not（或 shall not）的使用　在合同中使用上述词时要极其谨慎。权利义务的约定部分构成了合同的主体，这几个词如选用不当，就可能会引起纠纷。may 约定当事人的权利（可以做什么），shall 约定当事人的义务（应当做什么），must 用于强制性义务（必须做什么），may not（或 shall not）用于禁止性义务（不得做什么）。may do 不能说成 can do，shall do，should do 或 ought to do。may not do 在美国一些法律文件中可以用 shall not，但绝不能用 can not do 或 must not。

例如，在约定解决争议的途径时，可以说"The parties hereto shall, first of all, settle any dispute arising from or in connection with the contract by friendly negotiations. Should such negotiations fail, such dispute may be referred to the People's Court having jurisdiction on such dispute for settlement in the absence of any arbitration clause in the disputed contract or in default of agreement reached after such dispute occurs." 本句中的 shall 和 may 表达准确。出现争议后应当先行协商，所以采用了义务性"约定"，如果协商解决不了，作为当事人的权利，用选择性约定 may 也很妥当。本句可译为：双方首先应通过友好协商，解决因合同而发生的或与合同有关的争议。如果协商未果，合同中又无仲裁条款约定或争议发生后未就仲裁达成协议的，可将争议提交有管辖权的人民法院解决。

（2）用语正式　合同英语有着严肃的风格，与其他英语作品有很大不同。例如："因为"多用"by virtue of"，远远多于"due to"，一般不用"because of"；"在……之前"一般用"prior to"，而不用"before"；"关于"常用"as regards"，"concerning"或"relating to"，而不会用"about"；"事实上"用"in effect"，而不用"in fact"；"开始"用"com-

mencement”，而不用“start”或“begin”；“停止做”用“cease to do”，而不用“stop to do”；“其他事项”用“miscellaneous”，而不用“other matters/events”；“解释合同”用“construe a contract”或“comprehend a contract”，而不用“understand a contract”；“认为”用“deem”，用“consider”少，不用“think”或“believe”；“愿意做”用“intend to do”或“desire to do”，而不用“want to do”，“wish to do”。

（3）用语专业　合同用词不以大众是否理解和接受为转移，它是合同语言准确表达的保障。如合同出现的“瑕疵”（defect）、“救济”（remedy）、“不可抗力”（force majeure/Act of God）、“管辖”（jurisdiction）、“损毁”（damage）、“灭失”（loss）等就可能让非行业人士费解。另外几乎每个合同都少不了 hereinafter referred to as（以下简称），whereas（鉴于），in witness whereof（特此证明），for and on behalf of（谨代表），hereby（特此），thereof（它的）等虚词，这也是合同英语的一大特色。

（4）同义词、近义词、相关词的序列　同义词和近义词并列在英文合同里十分普遍，这是出于严谨和杜绝漏洞的考虑，有的也属于合同用语的固定模式。例如：“This agreement is made and entered into by and between Party A and Party B.”，句中“made and entered into”和“by and between”两组分别属于同义词和相关词并列。再例如：“Party A wishes to be released and discharged from agreement as from the effective date”一句中的“release”和“discharge”意思几乎相同。

常用的并列的词还有：ships and vessels（船舶）；support and maintenance（维护）；licenses and permits（许可证）；charges，fees，costs and expenses（各种费用）；any and all（所有的）；any duties，obligations or liabilities（任何义务或责任）；the partners，their heirs，successors and assigns（合伙人、继承人和受让人）；control and management of the partnership（合伙企业的控制和管理）；applicable laws，regulations，decrees，directives，and rules（适用法律、法规、法令、指令和规则）。

（5）拉丁词的使用　在英文合同中，拉丁词仍然是很常见的。例如，比例税率用“pro rate tax rate”要比“proportional tax rate”多，从事慈善性服务的律师用“pro bono lawyer”而不怎么用“lawyer engaged in charitable legal assistance”，委托代理人多用“agent ad litem”

2. 英文合同常用术语和句型

（1）英文合同常用术语见表 15-2。

表 15-2　英文合同常用术语

英　文	中　文	英　文	中　文
contract of employment	聘任（雇佣）合同	contract of purchase	订购合同
name of commodity	商品名称	quantity	数量
contract of trade	贸易合同	sales confirmation	成交确认书
specification	规格	unit price	单价
country of origin	生产国别	total value	总价值
port of loading/destination	装运/目的口岸	time of shipment	装运时间
term of payment	付款条件	guarantee period	保险期
letter of credit	信用证	shipping marks	装运标记

（续）

英　文	中　文	英　文	中　文
the buyer/sellers	买/卖方	the term of service	聘期，服务期
renew the contract	续约，延长合同期	manufacturer	生产厂家
packing	包装	partial shipment	分装
transshipment	转船	insurance	保险
compensation allowance	补偿津贴	claim indemnity	索赔
other terms	其他条款	engaging/engaged party	聘方/受聘方
expiration of the contract	合同到期	be covered by the seller	由卖方负责

（2）英文合同常用句型。

Hereafter to be called the first/second party.（以下称甲方/乙方。）

The undersigned seller and buyer have agreed to close the following transactions according to the terms and conditions stipulated below.（兹经买卖双方同意成交下列商品，特签订条款如下。）

To be effected by the seller covering all risks and war risk for 2.5% of invoice value.（由卖方按发票总值的2.5%投保综合险和战争险。）

On each package shall be stenciled conspicuously: port of destination, package number, net and gross weights, measurement and the shipping mark.（每件货物应明显标出到货口岸、件号、净重、毛重、尺码和装运标记。）

Any claim shall be lodged within 120 days from the date of import.（自进口日起，索赔期为120天。）

The present contract is executed in Chinese and English, both versions being equally valid.（本合同用中英文两种文字写成，两种版本具有同等效力。）

Neither party shall cancel the contract without sufficient cause or reason.（如无充足理由，双方均不得解除合同。）

If any other clause in this contract is conflict with the following supplementary conditions, the supplementary conditions should be taken as final and binding.（合同其他条款如与以下的附加条款相抵触时，以本附加条款为准。）

3. 英文协议书常用术语和句型

（1）英文协议书常用术语（见表15-3）

表15-3　英文协议书常用术语

英　文	中　文	英　文	中　文
agreement on academic exchange	学术交流协议	co-operation agreement on science and technology	科技合作协议
agreement on production co-operation	生产合作协议	agreement on personnel training	人员培训协议
patterns and contents of co-operation	合作方式与内容	measures of implementation	执行措施
Sino-foreign joint venture	中外合资	duration of agreement	协议有效期
personnel matters	人事	the two sides	双方
technical consultation	技术咨询	financial arrangements	费用安排

(2) 英文协议书常用句型。

conclude an agreement as follows（特签订如下协议）

go into effect (be effective) from the date of signature（自签字之日起生效）

The take-over will take place on...（验收将于某月某日进行）

...hereby indicate the intention to enter into a program of technological co-operation on the basis of mutual benefit (to benefit both sides)...（特此表明双方在互惠的基础上签订技术合作项目的愿望）

...provide equipment, technology, engineering technicians and managerial personnel including quality inspectors（……提供设备、技术、工程技术人员以及包括质量检验员在内的管理人员）

establish closer co-operation in technological transfer and information exchange（在技术转让和信息交流方面建立更为密切的合作关系）

must be completed 10 months after the conclusion of the present agreement（限在本协议签订后10个月内完成）

This agreement is hereby made on the basis of existing contact and consultation of both sides.（根据已有的联系和协商，双方特签订此协议。）

The two sides agree to co-operate with each other in research projects of common interest.（双方同意对共同感兴趣的项目进行合作。）

Detailed provisions concerning the co-operation will be worked out later through consultation.（有关合作细则，由双方日后另行商定。）

The provisions of this agreement may be amended at any time upon written consent of the participating co-operation.（合作双方可在任何时候经过书面协商同意后对本协议条款进行修改。）

At its expiration, the agreement may be modified or the period of validity may be extended through mutual consultation.（协议期满后，可通过相互协商，对协议进行修改或延长有效期。）

附 录

附录一 Words and Expressions

Unit 3

discipline [ˈdisəplin] *vt.* & *n.*	训练使有条理；纪律；学科；训练
subdiscipline [səbˈdisəplin] *n.*	分支
encompass [imˈkʌmpəs] *vt.*	围绕，包围；包含；完成
specialized [ˈspeʃəlaizd] *adj.*	专门的；专业的；专用的
biology [baiˈɔlədʒi] *n.*	生物学；生物
infrastructure [ˈinfrəstrʌktʃə(r)] *n.*	基础设施；基础建设
electrical circuit	电路
motor [ˈməutə(r)] *n.* & *vi.* & *vt.*	汽车；马达，发动机；开（乘）汽车
electromagnetic [iˌlektrəumægˈnetik] *adj.*	<物>电磁的
electromechanical [iˌlektrəumiˈkænikəl] *adj.*	电动机械的，机电的，电机的
optical fibers	光导纤维
optoelectronic [ˌɔptəuiˌlekˈtrɔnik] *adj.*	光电子的
telecommunication [ˌtelikəˌmju:niˈkeiʃn] *n.*	电信；电通信
instrumentation [ˌinstrəmenˈteiʃn] *n.*	仪器；手段
macroscopic [ˌmækrəˈskɔpik] *adj.*	宏观的；肉眼可见的
microscopic [ˌmaikrəˈskɔpik] *adj.*	微小的；微观的
enormous [iˈnɔ:məs] *adj.*	巨大的；极大的
microchip [ˈmaikrəutʃip] *n.*	微晶片；微型集成电路片
compressor [kəmˈpresə(r)] *n.*	压气机，压缩机
vacuum [ˈvækjuəm] *n.* & *v.*	真空；抽真空
vibration isolation	隔振
mechanical engineering	机械工程（学）
impetus [ˈimpitəs] *n.*	动力；促进
mechanic [məˈkænik] *n.*	技工，机修工
trial and error [ˈtraiəlændˈerə]	试错法；试差法
capital cost	投资成本

minimize [ˈminimaiz] *vt.*	把……减至最低数量（程度）；最小化
machine tool	机床
principal [ˈprinsəpl] *adj. & n.*	主要的，最重要的；负责人，主角
conveyor [kənˈveiə(r)] *n.*	传送带；传送者
in hand	在手中，有关系；手持
versatile [ˈvə:sətail] *adj.*	多功能的；多用途的，通用的
batch production	批量生产
presuppose [ˌpri:səˈpəuz] *vt.*	预先假定；以……为先决条件；意味着
augment [ɔ:gˈment] *vt. & n.*	增强，扩大；增加，补充物
witness [ˈwitnəs] *n. & vt. & vi.*	目击者，见证人；见证
turbine [ˈtə:bain] *n.*	汽轮机；涡轮机；透平机
acquire [əˈkwaiə(r)] *vt.*	学到；获得，取得
reliability [riˌlaiəˈbiləti] *n.*	可靠，可信赖
sophisticated [səˈfistikeitid] *adj.*	（sophisticate 的过去分词形式） 复杂的；有经验的
hydraulic [haiˈdrɔ:lik] *adj.*	水力的，水压的；水力学的
reciprocate [riˈsiprəkeit] *vt. & vi.*	互换；往复运动
rotary [ˈrəutəri] *adj. & n.*	旋转的；旋转式机器
artificial limb	假肢
touch feedback	接触反射
spare-part	备件，备用部分
ventilate [ˈventileit] *vt.*	通风；使通风
ubiquitous [ju:ˈbikwitəs] *adj.*	无所不在的；普遍存在的
side effect	副作用
dereliction [ˌderəˈlikʃn] *n.*	废弃，放弃；玩忽职守
pollutant [pəˈlu:tənt] *n.*	污染物
dynamics [daiˈnæmiks] *n.*	动态；动力学，力学
thermodynamics [ˌθə:məudaiˈnæmiks] *n.*	热力学
lubrication [ˌlu:briˈkeiʃn] *n.*	润滑，加油；油润
bring about	实现；造成，引起；创造
synthesize [ˈsinθəsaiz] *vt. & vi.*	综合；人工合成；合成
viability [ˌvaiəˈbiləti] *n.*	生存能力，发育能力；生活力
reputation [ˌrepjuˈteiʃn] *n.*	名声；信誉，声望
intuitive [inˈtju:itiv] *adj.*	直观的；直觉的
professionalism [prəˈfeʃənəlizəm] *n.*	职业化；职业水准或特性
operations research	运筹学
value engineering	价值工程
PABLA	逻辑法问题分析
rationalize [ˈræʃnəlaiz] *vt.*	使合理化；据理解释

exponential [ˌekspəˈnenʃl] *n.* & *adj.* 指数；指数的，幂数的；越来越快的
formidable [ˈfɔːmidəbl] *adj.* 可怕的；令人敬畏的；难以对付的
exhaustion [igˈzɔːstʃən] *n.* 疲惫，衰竭；枯竭，用尽；排空
grasp [grɑːsp] *vt.* & *vi.* & *n.* 抓住；了解；控制；（与 at 连用）攫取；（与 for 连用）急切地寻求
principle [ˈprinsəpl] *n.* 原则，原理；准则，道义
analytical [ˌænəˈlitikl] *adj.* 分析的，分析法的；善于分析的
detailed-oriented *adj.* 细致的
seminar [ˈseminɑː(r)] *n.* 研讨会；研讨班，讲习会；培训会
workshop [ˈwəːkʃɔp] *n.* 车间；专题讨论会，研究会
abreast [əˈbrest] *adv.* & *adj.* 并排；并列，并肩地；不落后于
lay off 暂时解雇，裁员；停止工作
well-rounded *adj.* 丰满的；多才多艺的；面面俱到的
expertise [ˌekspəːˈtiːz] *n.* 专门知识或技能；专家意见，评价
chart [tʃɑːt] *n.* & *vt.* 图表；排行榜；绘制地图；记录；记述
engineering drawings 工程制图
memoranda [ˌmeməˈrændə] *n.* （memorandum 的名词复数）备忘录
executive [igˈzekjətiv] *n.* & *adj.* 总经理；执行指令；执行的；管理的；政府部门的
adept [əˈdept] *adj.* （at）精于……的，擅长于……的；巧妙的
discipline-specific *adj.* 特定学科的
interpersonal [ˌintəˈpəːsənl] *adj.* 人际的；人与人之间的
fit [fit] *vt.* & *vi.* & *adj.* & *n.* 安装；合身；合适的；匹配
coordination [kəuˌɔːdiˈneiʃn] *n.* 协调；和谐

Unit 4

nomography [nəuˈmɔgrəfi] *n.* 图解构成术
orthographic representation 正视表示法
depict [diˈpikt] *vt.* 描述；描绘，描画
oblique view 斜视图
pictorial view 插图，视图
sectional view 剖视图
mylar [ˈmaiˌlɑː] *n.* 聚酯薄膜
blueprint [ˈbluːprint] *n.* & *vt.* 蓝图，设计图；为……制蓝图
ammonia [əˈməuniə] *n.* 氨；氨水；氨气
ammonia-developed *adj.* 氨水显影的
diazo [daiˈæzəu] *n.* & *adj.* 重氮基；二氮化合物的
lithography [liˈθɔgrəfi] *n.* 石印；平版印刷术
section-lining/ cross-hatching 剖面线

knurl [nə:l] *n.*	滚花；硬节
thread [θred] *n.* & *vt.*	螺纹；线；将（针、线等）穿过……
dimension [di'menʃən] *n.* & *adj.* & *vt.*	尺寸；维；标出尺寸
fabricate ['fæbrikeit] *vt.*	制造；捏造；装配
referenced to	与……相关的
leader ['li:də(r)] *n.*	引线
inclined [in'klaind] *adj.*	倾斜的；倾向的
lowercase/ uppercase ['ləuəkeis] / ['ʌpəkeis]	*adj.* 小写的/大写的
align [ə'lain] *vt.* & *vi.*	使成一线；排整齐
unidirectional [ˌju:nidi'rekʃənəl] *adj.*	单向的，单向性的
horizontally [ˌhɔri'zɔntəli] *adv.*	水平地，横地
fraction ['frækʃn] *n.*	分数；一小部分，些微；片段
tolerance ['tɔlərəns] *n.*	公差；容忍；限度
layout drawing	布局图，布置图；布线图
aisle [ail] *n.*	过道，通道；狭长的通路
to scale	按比例
aluminum [ə'lju:minəm] *n.*	铝
photosensitized [ˌfəutəu'sensitaizd] *adj.*	光敏的
detail drawing	详图；零件图
preliminary [pri'liminəri] *adj.* & *n.*	初步的，初级的；预备的；准备工作
assembly drawing	装配图，组装图
judicious [dʒu'diʃəs] *adj.*	明智的；审慎的；判断正确的
pertinent ['pə:tinənt] *adj.*	有关的；恰当的；切题的
schematic drawing	示意图
fixture ['fikstʃə(r)] *n.*	固定装置，夹具
Etched-circuit	蚀刻电路
flow diagram	流程图
structural drawing	结构图
embody [im'bɔdi] *vt.*	表现，象征；包含，收录；使具体化
terminology [ˌtə:mi'nɔlədʒi] *n.*	专门名词；术语，术语学；用辞
first - angle projection	第一角投影；第一象限投影法
radiograph ['reidiəugrf] *n.*	射线照片，X 光照片
third - angle projection	第三角投影；第三象限投影法
pivot ['pivət] *n.* & *vi.* & *vt.*	枢轴；在枢轴上转动；绕枢轴旋转
transparent [træns'pærənt] *adj.*	透明的；清澈的；显而易见的
auxiliary view	辅助视图
orthographic view	正视图
allow for	允许有；考虑到；体谅；留出
perpendicular [ˌpiə:p(ə)n'dikjulə] *adj.* & *n.*	垂直的，正交的；直立的；垂线

isometric view	等距视图；等轴测试图
compass [ˈkʌmpəs] *n.*	罗盘；指南针；圆规；界限
perplex [pəˈpleks] *vt.*	使迷惑，使混乱；使复杂化
mechanism [ˈmekənizəm] *n.*	机构；机械装置
longitudinal section	纵剖面
designate [ˈdezigneit] *vt.*	指派；指明，指出；表明，意味着
full section, half section, broken section	全剖视图；半剖视图；局部剖视图
omit [əˈmit] *vt.*	省略；遗漏；删掉；未（做）
sparingly [ˈspɛəriŋli] *adv.*	保守地；节约地；仁慈地；缺少地
solid object line	实线
draftsman [ˈdrɑːftsmən] *n.*	起草人，立案者，绘图员
center line	中心线
denote [diˈnəut] *vt.*	代表；指代；预示；意思是
irregular [iˈregjələ(r)] *adj.*	不规则的，不对称的；无规律的
boundary [ˈbəundri] *n.*	分界线；范围；边界线

Unit 5

gravitational [ˌgræviˈteiʃənəl] *adj.*	重力的，引力的
magnitude [ˈmægnitjuːd] *n.*	大小；量级
idealizations [aiˌdiəliˈzeʃən] *n.*	理想化；理想化的事物
particle [ˈpɑːtik(ə)l] *n.*	颗粒；质点；极小量
perpendicular [ˌpiəːp(ə)nˈdikjulə] *adj. & n.*	垂直的，正交的；直立的；垂线
algebra [ˈældʒibrə] *n.*	代数学
arbitrary [ˈɑːbit(rə)ri] *adj.*	任意的；专制的
equilibrium [ˌiːkwiˈlibriəm; ˌekwi-] *n.*	均衡；平静；保持平衡的能力
loadings [ˈləudiŋs] *n.*	载荷；荷量
kinetic friction	动摩擦
collinear [kəˈliniə] *adj.*	共线的；同线的；在同一直线上的
parallelogram law	平行四边形定律
parallelogram [ˌpærəˈleləgræm] *n.*	平行四边形
diagonal [daiˈæg(ə)n(ə)l] *adj. & n.*	斜的；对角线的；对角线；斜线
resultant force	合力
triangle [ˈtraiæŋg(ə)l] *n.*	三角（形）；三角关系；三角形之物
torsional [ˈtɔːʃənəl] *adj.*	扭转的；扭力的
shear stress	切应力
tangent [ˈtændʒənt] *adj. & n.*	切线的，相切的；切线，正切
ductile [ˈdʌktail] *adj.*	柔软的；易延展的
brittle [ˈbrit(ə)l] *adj.*	易碎的，脆弱的
deformable [diˈfɔːməbl] *adj.*	可变形的

axial tensile	轴向拉伸
longitudinal [ˌlɔndʒiˈtjuːdinəl] *adj.*	长度的，纵向的；经线的
isotropic [ˌaisə(u)ˈtrɔpik] *adj.*	各向同性的；等方性的
vice versa [ˌvaisiˈvəːsə]	反之亦然
dimension [diˈmenʃ(ə)n; dai-] *n.*	方面；维；尺寸；次元；容积
whereas [wɛərˈæz] *conj.*	然而；鉴于；反之
cross-sectional [krɔsˈsekʃənl] *adj.*	横截面的
cantilevered [ˈkæntiliːvəd] *adj.*	悬臂式的
centroid [ˈsentrɔid] *n.*	形心；质心
statically equivalent load	静态等效负载
superposition [ˌsjuːpəpəˈziʃən] *n.*	叠加，重合
neutral [ˈnjuːtr(ə)l] *adj. & n.*	中立的，中性的；中立者；齿轮的空档
reciprocal [riˈsiprək(ə)l] *adj. & n.*	互惠的；相互的；倒数的；倒数
density [ˈdensiti] *n.*	密度
dimensionless [daiˈmenʃənlis] *adj. & n.*	无量纲的；无因次的
viscosity [viˈskɔsiti] *n.*	黏性，黏度
cohesion [kə(u)ˈhiːʒ (ə) n] *n.*	凝聚；结合；内聚力
adhesion [ədˈhiːʒ(ə)n] *n.*	黏附；支持；固守
molecular [məˈlekjulə] *adj.*	分子的；由分子组成的
immiscible [iˈmisib(ə)l] *adj.*	不融和的；不能混合的
out-of-balance *adj.*	不平衡的
prototype [ˈprəutətaip] *n.*	原型；标准，模范
kinematic similarity	运动相似
capillarity [ˌkæpiˈlæriti] *n.*	毛细管作用，毛细管现象
pipe [paip] *n. & vi. & vt.*	管；烟斗；笛；吹笛；用管道输送
frictionless [ˈfrikʃnles] *adj.*	无摩擦的；光滑的
pitot tube	皮托管（流速计）；皮托静压管
approximate [əˈprɔksimət] *vt. & vi. & adj.*	近似；使……接近；粗略估计；近似的
hypothetical [ˌhaipəˈθetik(ə)l] *adj.*	假设的
centrifugal pump	离心抽机，离心泵
impeller [imˈpelə] *n.*	叶轮；推进者
coaxial [kəuˈæksiəl] *adj.*	同轴的，共轴的
clogged [klɔgd] *adj. & v.*	阻塞的；堵住的；阻塞；妨碍
horizontal [ˌhɔriˈzɔnt(ə)l] *adj. & n.*	水平的；地平线的；水平线，水平面
backflow [ˈbækfləu] *n.*	回流；逆流
debris [ˈdebriː; ˈdeibriː] *n.*	碎片，残骸
axial-flow [ˌæksiəlˈfləu], *adj.*	轴向流动的
impulse turbine	冲力式涡轮机；冲击式汽轮机
impinge [imˈpin(d)ʒ] *vi. & vt.*	撞击；侵犯；撞击

reaction turbine 反动式涡轮机；反动式汽轮机
hydraulic [haiˈdrɔːlik; haiˈdrɔlik] *adj.* 液压的；水力的；水力学的
abstraction [əbˈstrækʃ(ə)n] *n.* 抽象；提取；抽象概念；空想
anthropomorphic [ænθrəpəˈmɔːfik] *adj.* 拟人的，赋予人性的
statistical [stəˈtistik(ə)l] *adj.* 统计的；统计学的
vibration [vaiˈbreiʃ(ə)n] *n.* 振动
ambiguity [æmbiˈgjuːiti] *n.* 含糊；不明确
zeroth law of thermodynamics 热力学第零定律
Celsius scale 摄氏温度标
thermocouple [ˈθiəːməukʌp(ə)l] *n.* 热电偶
calibrate [ˈkælibreit] *vt.* 校正；调整
emf *abbr.* 电动势（Electromotive Force）
thermal emf 热电动势
imprecision [ˌimpriˈsiʒən] *n.* 不精确；不严密
platinum resistance thermometer 铂电阻温度计
diathermic [ˌdaiəˈθiəːmik] *adj.* 透热性的；电疗法的
hydrostatic [ˌhaidrə(u)ˈstætik] *adj.* 流体静力学的；静水力学的
isothermal process 等温过程
adiabatic [ˌeidaiəˈbætik;, ædiə-] *adj.* 绝热的；隔热的
peculiarity [piˌkjuːliˈæriti] *n.* 特性；特质；奇特
deduction [diˈdʌkʃ(ə)n] *n.* 扣除，减除；推论；减除额
formulation [fɔːmjuˈleiʃn] *n.* 构想，形式；公式化

Unit 6

discipline [ˈdisəplin] *vt.* & *n.* 训练；纪律；学科；训练
engineering design 工程设计
concoct [kənˈkɔkt] *vt.* 捏造；混合而制；调和
ideation [ˌaidiˈeiʃ(ə)n] *n.* 构思能力，思维能力；构思过程
recast [riːˈkɑːst] *vt.* & *n.* 重铸；彻底改动；重做的事物
coherent [kə(u)ˈhiər(ə)nt] *adj.* 连贯的；互相耦合的；黏在一起的
concise [kənˈsais] *adj.* 简明的，简洁的
embodiment [imˈbɔdimənt] *n.* 体现；化身；具体化
trait [treit; trei] *n.* 特性，特点；品质；少许
suppressed [səˈprest] *adj.* & *v.* 抑制的，发育不全的；镇压，禁止
decision matrix 决策矩阵；抉择矩阵
perseverance [pəːsiˈviər(ə)ns] *n.* 坚持不懈；不屈不挠；耐性；毅力
version [ˈvəːʃ(ə)n] *n.* 版本；译文
widget [ˈwidʒit] *n.* 装饰物；小机械；小部件
iterate [ˈitəreit] *vt.* 迭代；重复；反复说；重做

kinematic chain	运动链
assemblage [əˈsemblidʒ] *n.*	装配；集合；聚集；集合物
degrees of freedom (DOF)	自由度
synthesis [ˈsinθisis] *n.*	综合；合成；综合体
mobility [məuˈbiləti] *n.*	移动性；机动性；迁移率
binary link	二副元素构件
curvilinear [ˌkə:viˈliniə] *adj.*	曲线的；由曲线组成的
rectilinear [ˌrektiˈliniə] *adj.*	直线运动的；形成直线的
kinematic pairs	运动对偶，运动副
ternary link	三副元素构件
lubricant [ˈlu:brik(ə)nt] *n. & adj.*	润滑剂；润滑油；润滑的
enveloping surfaces	包络面；包围面
prismatic [prizˈmætik] *adj.*	棱柱的，棱镜的；
slider joint	滑动副
paradoxically [ˌpærəˈdɔksikəli] *adv.*	自相矛盾地；似非而是地；反常地
denominator [diˈnɔmineitə] *n.*	分母；共同特征或共同性质
toolkit [ˈtu:lkit] *n.*	工具包，工具箱
coalesce [ˌkəuəˈles] *vi. & vt.*	合并；结合；联合；使……联合
dwell [dwel] *vi.*	居住；存在于；停留；停顿
crank [kræŋk] *n. & vt.*	曲柄；装曲柄
geneva wheel	槽轮；马尔特机构间歇传动轮
ratchet [ˈrætʃit] *n. & vt.*	棘轮；棘齿；安装棘轮于；松脱
ratchet and pawl mechanism	棘轮与棘爪机构
wrench [rentʃ] *n. & v.*	扳手；猛扭；歪曲；使痛苦
winch [wintʃ] *n.*	绞盘；绞车起货机
inversion [inˈvə:ʃ(ə)n] *n.*	倒置；反向；倒转
mechanism inversion	机构倒置
trade-off *n.*	权衡；交易；物物交换
rocker [ˈrɔkə] *n.*	摇杆；套钩；摇轴
parasitic [pærəˈsitik] *adj.*	寄生的
precess [priˈses] *vt.*	使产生进动
groove [gru:v] *n. & vt. & vi.*	凹槽；最佳状态；惯例；开槽于
resonance [ˈrez(ə)nəns] *n.*	共振；共鸣；反响
crossover [ˈkrɔsəuvə] *n.*	交叉；天桥；转线路
local wean	局部断裂
tappet [ˈtæpit] *n.*	挺杆；梃杆；凸轮从动件
chrome plating	镀铬
literally [ˈlit(ə)rəli] *adv.*	照字面地；逐字地；正确地；简直
immersed [iˈmə:st] *adj. & v.*	浸入的；专注的；浸；沉湎于

contamination [kən，tæmi'neiʃən] *n.*	污染，玷污；污染物
eschew [is'tʃu:; es-] *vt.*	避免；避开；远避
hypoid ['haipɔid] *adj.*	准双曲面的；交错轴齿轮的
gear train	轮系；齿轮传动链
spur gear	直齿轮
helical ['helik(ə)l; 'hi:-] *adj.*	螺旋形的
bevel gear	锥齿轮机构；扇形齿轮；锥齿轮
pinion ['pinjən] *n. & vt.*	小齿轮；绑住，束缚
epicyclic train	周转齿轮系
compound train	复合轮系
epicyclic [ˌepi'saiklik] *adj.*	本轮的；周转圆的
planetary train	行星齿轮系
kinetics [ki'netiks；kai-] *n.*	动力学
massless ['mæslis] *adj.*	无质量的
mass moment	质量矩
inertia [i'nə:ʃə] *n.*	惯性
invariant [in'veəriənt] *adj. & n.*	不变的；不变量；不变式
stiffness ['stifnis] *n.*	刚度
the first moment of mass	一阶质量矩
second moment of mass	惯性极矩
radius of gyration	回转半径
damping ['dæmpiŋ] *n. & v.*	阻尼；衰减，减幅；抑制
damper ['dæmpə] *n.*	阻尼器；减振器；气闸
superposition [ˌsju:pəpə'ziʃən] *n.*	叠加，重合
simultaneous equation	联立方程
virtual work	虚功
external force	外力；外部力量
implement ['implim(ə)nt] *vt.*	实施，执行；实现，使生效
dwarf [dwɔ:f] *vi. & n. & vt. & adj.*	变矮小；矮子；使矮小；矮小的
external torque	外转矩
impinge [im'pin(d)ʒ] *vi. & vt.*	撞击；侵犯；撞击

Unit 7

enumerate [i'nju:məreit] *vt.*	枚举
creep [kri:p] *vi. & n.*	爬行；蔓延；慢慢地移动；爬行
manifest ['mænifest] *vt. & vi. & n. & adj.*	证明，表明；显示；出现；载货单；显然的
encompass [in'kʌmpəs；en-] *vt.*	包含；包围，环绕；完成
phenomenological theory	唯象理论
circumvent [sə:kəm'vent] *vt.*	包围；陷害；绕行

yielding failure	屈服失效
modulus [ˈmɔdjuləs] *n.*	系数；模数
specimen [ˈspesimin] *n.*	样品，样本；标本
yield point stress	屈服点应力
maximum normal stress theory of failure	理论最大失效正应力
setscrew [ˈsetskruː] *n.*	固定螺钉
taper pin	锥形销
coupling [ˈkʌpliŋ] *n. & v.*	耦合；结合；连接
alignment [əˈlainm(ə)nt] *n.*	队列，成直线；校准
spring [spriŋ] *vi. & vt.*	生长；涌出；跃出；裂开；使跳起
rubber [ˈrʌbə] *n. & adj. & vt.*	橡胶；橡皮；橡胶制成的；用橡胶制造
cushion [ˈkuʃ(ə)n] *n. & vt.*	垫子；给……安上垫子；缓和……的冲击
collinear [kəˈliniə] *adj.*	共线的；同线的；在同一直线上的
plain-carbon steel	普通碳钢；碳素钢
normalizing [ˈnɔrmlˌaiz] *n. & v.*	正火；使正常化；对钢正火
annealing [əˈniliŋ] *n. & v.*	热处理；低温退火；退火
cold-drawn *adj.*	冷拔的
low-carbon steel	低碳钢
free-cutting steel	易切削钢；高速切削钢
mechanism [ˈmek(ə)niz(ə)m] *n.*	机制；原理，途径；进程；机械装置
music wire	琴用钢丝
prohibitive [prə(u)ˈhibitiv] *adj.*	禁止的，禁止性的；抑制的；过高的
tensile strength	抗张强度；抗拉强度
corrosion resistance	耐蚀性；抗腐蚀性
creep-resistant	抗蠕变
triangle metric thread	三角形公制螺纹
nominal diameter	公称直径
thread pitch	螺距
lead screw	导螺杆；丝杠
acme thread	梯形螺纹，爱克米螺纹
fluid-tight *adj.*	密封的；不漏的，不透水的
pitch diameter	节圆直径
pitch [pitʃ] *vi. & vt. & n.*	螺距
single-thread	单线程；单线螺纹；单头螺纹
double-thread	双线螺纹；双头螺纹
multiple-thread screws	多头螺纹螺钉
lead [liːd] *n.*	导程
rayon [ˈreiɔn] *n.*	人造丝；人造纤维
pulley [ˈpuli] *n. & vt.*	滑轮；带轮；滑车；用滑轮升起

tractive force	牵引力；驱动力
grease [griːs] *vt. & n.*	涂脂于；油脂
idler sprocket	张紧链轮
slack [slæk] *adj. & vi. & vt. & adv.*	松弛的；松懈；减弱；放松；使缓慢
overhanging [əuvəˈhæŋiŋ] *n. & v. & adj.*	悬伸，突出；外悬；悬于……之上；悬伸的
span [spæn] *n. & vt.*	跨度，跨距；范围；跨越；持续
chain wrap	链传动包角
seizure [ˈsiːʒə] *n.*	没收；夺取；捕获
lubrication [ˌluːbriˈkeiʃən] *n.*	润滑；润滑作用
impending [imˈpendiŋ] *adj. & v.*	即将发生的；悬挂的；迫近；悬空
stick slip	黏滑运动
contaminated [kənˈtæməneitid] *adj. & v.*	受污染的；弄脏的；污染
running-inperiod	磨合期
fatty acid	脂肪酸
journal [ˈdʒəːn(ə)l] *n.*	轴颈
tin-and lead-base babbitt	锡和铅基巴氏合金
bronze bearing	青铜轴承
copper-lead bearing	铜铅合金轴承
conformability [kənfɔrməˈbiliti] *n.*	一致；适合；顺应
cast iron bearing	铸铁轴承
porous bearing	多孔轴承
sintering [ˈsintəriŋ] *n. & v. & adj.*	烧结；使熔结；烧结的
felt washer	毡垫圈，油封；毛毯洗涤槽
carbon and plastic bearing	碳和塑料轴承
teflon [ˈtefˈlɔn] *n.*	聚四氟乙烯
liner [ˈlainə] *n.*	班轮，班机；衬垫
laminated phenolic bearing	叠层酚醛轴承
lignum vitae [ˈvaitiː]	愈疮树
bonded coating	胶粘涂料
molybdenum disulfide	二硫化钼
curvilinear [ˌkəːviˈliniə] *adj.*	曲线的；由曲线组成的
designated [ˈdezigˌnetid] *adj.*	指定的；特指的
thrust [θrʌst] *n. & vt. & vi.*	推力；刺；插入；推挤；猛然或用力推
load rating	额定载荷；载重率
basic rating load	基本额定负荷
reliability [riˌlaiəˈbiləti] *n.*	可靠性
flooded lubrication	浸没润滑
scanty [ˈskænti] *adj.*	缺乏的；吝啬的；仅有的；稀疏的
churn [tʃəːn] *vi. & vt.*	搅拌；搅动

press fit	压配合；压力装配
preloaded ball bearing	预紧滚珠轴承
flange [flændʒ] *n.*	法兰盘；凸缘
deficiency [diˈfiʃ(ə)nsi] *n.*	缺陷，缺点；缺乏
spherical roller bearing	球面滚子轴承；球形滚柱轴承
flexible roller bearing	挠性滚柱轴承
needle bearing	滚针轴承
carburizing or case hardening	硬化或表面硬化
nitriding [ˈnaitridiŋ] *v. & n.*	渗氮；渗氮法
ammonia gas	氨气
induction and flame hardening	感应淬火和火焰淬火
teeth blank	齿坯
tooth breakage	齿轮折断
surface pitting	表面点蚀
scoring [ˈskɔːriŋ] *n. & v.*	得分；刻痕；记下
accentuate [əkˈsentʃueit; -tju-] *vt.*	强调；重读
helical gear	斜齿轮
bevel gear	锥齿轮，锥形齿轮
cones [kəunz] *n. & v.*	锥形体；使成锥形；使成斜角
worm gear	蜗轮；螺旋齿轮

Unit 8

ferrous/nonferrous metal	钢铁金属/非铁金属
impurity [imˈpjuərəti] *n.*	污点；掺杂，杂质
nonmetallic [ˈnɔnmiˈtælik] *adj. & n.*	非金属的；非金属物质
natural rubber	天然橡胶
ceramics [siˈræmiks] *n.*	制陶术；陶瓷
semiconductor [ˌsemikənˈdʌktə (r)] *n.*	半导体
composite material	复合材料
cast iron	铸铁
heat treatment	热处理
plain carbon steel	普通碳钢
silicon [ˈsilikən] *n.*	硅；硅元素
sulphur [ˈsʌlfə(r)] *n. & v.*	硫黄；硫黄色；使硫化
phosphorus [ˈfɔsfərəs] *n.*	磷；磷光体
manganese [ˈmæŋgəniːz] *n.*	锰
nickel [ˈnikl] *n. & vt.*	镍；镀镍于
chromium [ˈkrəumiəm] *n.*	铬
molybdenum [məˈlibdənəm] *n.*	钼

vanadium [və'neidiəm] *n.*	钒，铅矿
tungsten ['tʌŋstən] *n.*	钨
hardness [hɑ:dnəs] *n.*	坚硬；硬度；困难
ductility [dʌk'tiliti] *n.*	韧性；展延性，顺从
spring [spriŋ] *n. & vi. & vt.*	春季；泉水；弹簧；跳跃；突然出现
die [dai] *n.*	钢型，硬模；骰子
metallurgist [mə'tælədʒist] *n.*	冶金家，冶金学者
toughness [tʌfnəs] *n.*	韧性；坚韧；刚性
brittleness ['britlnəs] *n.*	脆性，脆度；脆弱性
roll [rəul] *vt. & vi. & n.*	滚动；辗；转动；翻滚
impact resistance	抗冲击强度
detrimental [ˌdetri'mentl] *adj. & n.*	有害的；不利的；（或物）有害的人
hot working	热加工
resulphurize ['ri:'sʌlfjuraiz] *v.*	再硫化，再用硫处理
undesirable [ˌʌndi'zaiərəbl] *adj. & n.*	不良的；不合需要的；不良分子
dissolve [di'zɔlv] *vt. & vi.*	使溶解；使液化；消除；溶解；分解
yield point	屈服点
susceptible [sə'septəbl] *adj.*	易受影响的；易受感染的
warp [wɔ:p] *n. & vt. & vi.*	弯曲；弄弯，变歪；扭曲，曲解
scale [skeil] *n. & vt. & vi.*	规模；比例；测量；生水垢；氧化
corrosion resistance	抗腐蚀强度
wear resistance	耐磨强度
elastic limit	弹性极限
ultimate strength	极限强度
tool-and-die steel	模具工具钢
chisel ['tʃizl] *n. & vt. & vi.*	凿子，錾子；凿，雕
screwdriver ['skru:draivə(r)] *n.*	螺丝刀；改锥
cold-finished steel	冷加工精整钢
surface finish	表面粗糙度
drill rod	钻杆
grinding ['graindiŋ] *adj. & n.*	磨的，摩擦的；磨削
polish ['pɔliʃ] *v. & n.*	磨光；润色；抛光
hexagonal [heks'ægənl] *adj.*	六方；六角形的，六边形的
white iron	白口铸铁
gray iron	灰口铸铁
malleable iron ['mæli:əbəl 'aiən]	展性铸铁；可锻铸铁
plumbing ['plʌmiŋ] *n.*	水管装置；管道工程
nodular iron	球状石墨铸铁
compressive strength	抗压强度

polymer [ˈpɔlimə(r)] *n.*	多聚物；聚合物
elastomer [iˈlæstəmə(r)] *n.*	弹性体，人造橡胶
resin [ˈrezin] *n. & vt.*	树脂；合成树脂；松香；用树脂处理
embed [imˈbed] *vt. & vi.*	把……嵌入；栽种
laminated [ˈlæmineitid] *adj.*	由薄片叠成的
thermosetting [ˈθəːməuˌsetiŋ] *adj.*	热固；热硬化性的
thermoplastic [ˌθəːməuˈplæstik] *adj. & n.*	热塑性的；热塑性塑料
cure [kjuə(r)] *vi. & vt.*	加工处理
irreversible [ˌiriˈvəːsəbl] *adj.*	不可逆的；不能翻转的
cross-linking	交联；交叉连接
exotherm [ˈeksəuθəːm] *n.*	放热曲线；放热
cavity [ˈkævəti] *n.*	腔，洞
thermal aging	热力老化
degradation [ˌdegrəˈdeiʃn] *n.*	恶化；降解；老化
spectrum [ˈspektrəm] *n.*	光谱；波谱；范围；系列
synthetic [sinˈθetik] *adj. & n.*	合成的；人造的；合成物；合成纤维
graphite [ˈgræfait] *n.*	石墨，黑铅
charcoal [ˈtʃɑːkəul] *n.*	木炭
coke [kəuk] *n.*	焦炭，焦煤
amorphous [əˈmɔːfəs] *adj.*	无组织的；非结晶的
specific electrical resistance	比电阻
electrolytic [iˌlektrəˈlitik] *adj.*	电解质；电解的
crucible [ˈkruːsibl] *n.*	坩埚
stock [stɔk] *n. & adj. & vt.*	库存，备料；股票；常备的；提供货物
electrical insulator	电绝缘体
transparency [trænsˈpærənsi] *n.*	透明度；透明；透明性；透明的东西
germanium [dʒəːˈmeiniəm] *n.*	锗
gallium arsenide [ˈgæliəm ˈɑːsənaid]	砷化镓
transistor [trænˈzistə(r)] *n.*	晶体管；晶体管收音机
diode [ˈdaiəud] *n.*	二极管
blend [blend] *vt. & vi. & n.*	混合；调和；协调；混合物；混合色
plywood [ˈplaiwud] *n.*	胶合板，合板，夹板
shatter [ˈʃætə(r)] *vt. & v. & n.*	使破碎，使碎裂；粉碎；碎片
biological [ˌbaiəˈlɔdʒikl] *adj. & n.*	生物的；生物学的；生物制品
optical [ˈɔptikl] *adj.*	光学的；视觉的；眼睛的
copper [ˈkɔpə(r)] *n. & adj. & vt.*	铜；铜币；铜制的；镀铜
space shuttle	航天飞机
booster rocket	助推火箭
silica [ˈsilikə] *n.*	硅石，二氧化硅；硅氧

hydroxyapatite [haidrɔksiˈæpətait] *n.*	羟磷灰石
cardiovascular [ˌkɑːdiəuˈvæskjələ(r)] *adj.*	心血管的
cardiovascular stent	心血管支架
orthodontic brace	正畸支具
lead zirconium titanate	钛锆酸铅
resonance [ˈrezənəns] *n.*	共振；共鸣；反响
superconductor [ˈsuːpəkəndʌktə(r)] *n.*	超导体
dielectric [ˌdaiiˈlektrik] *n.* & *adj.*	电介质，绝缘体；非传导性的
capacitor [kəˈpæsitə(r)] *n.*	电容器，电容
uranium dioxide [juəˈreinjəm daiˈɔksaid]	二氧化铀
plutonium [pluːˈtəuniəm] *n.*	钚
fuel cell	燃料电池
catalyst substrate	催化剂载体
deposit [diˈpɔzit] n. & *vt.* & *vi.*	存款；沉淀物；寄存；沉淀
ferrite [ˈferait] *n.*	铁氧体；铁酸盐，铁素体
inductor [inˈdʌktə] *n.*	感应器；诱体；感应体
transformer [trænsˈfɔːmə(r)] *n.*	变压器
yttrium aluminum garnet [ˈitriəm əˈluːmənəm ˈgɑːnit]	钇铝柘榴石
photovoltaic [fəutəuvɔlˈteiik] *adj.*	光电池的
liquid crystal display (LCD)	液晶显示
humidity [hjuːˈmidəti] *n.*	湿度；潮湿
passively [ˈpæsivli] *adv.*	被动地，顺从地
shape-memory alloy	形状记忆合金
gas grill	瓦斯烧烤炉
magnetorheological [mægniːtəhiəlɔdʒiˈkɑːl]	磁流变
suspension system	悬架系统，悬架装置
photochromic [fəutəˈkrəumik] *adj.*	光致变色；光色；对光反应变色的
automatic dimming mirror	自动调光镜
torsional strength	抗扭强度
shear strength	切变强度
applied load	外部载荷
stress [stres] *n.* & *vt.*	压力；应力；给……加压力
strain [strein] *n.*	应变
elasticity [ˌiːlæˈstisəti] *n.*	弹性；弹力；灵活性；伸缩性
modulus of elasticity	弹性模量
bending strength	抗弯强度
deflect [diˈflekt] *vt.* & *vi.*	使歪斜；使弯曲；偏转，偏离
alternating stress	交变应力
back and forth	来回地，往复地

indentation [ˌindenˈteiʃn] *n.* 缺口；凹进；缩格；凹口
indenter [inˈdentə] *n.* 压头
cryogenic [ˌkraiəˈdʒenik] *adj.* 低温学的
hardening [ˈhɑːdniŋ] *n.* 淬火；硬化
tempering [ˈtempəriŋ] *n.* 回火
annealing [əˈniːliŋ] *n.* 退火
case hardening 表面淬火，表面硬化
quench [kwentʃ] *vt.* 骤冷；淬火
retain [riˈtein] *vt.* 保持；保留
pyrometer [paiˈrɔmitə] *n.* 高温计
soak [səuk] *vt.* & *vi.* & *n.* 浸泡，浸透；吸入
tong [tɔŋ] *n.* & *v.* 钳；用钳子钳起
abrasive [əˈbreisiv] *adj.* & *n.* 研磨的；研磨料
carburizing [ˈkɑːbjuraiziŋ] *n.* 增碳剂，渗碳剂；渗碳
piston pin 活塞销

Unit 9

casting [ˈkɑːstiŋ] *n.* 铸造；铸件
refractory [riˈfrækt(ə)ri] *adj.* & *n.* 难熔的；耐火物质
directional properties 各向异性
alloy [ˈælɔi] *n.* 合金
forging [ˈfɔːdʒiŋ] *n.* 锻造；锻件
metallurgical [ˌmetəˈləːdʒikl] *adj.* 冶金的；冶金学的
foundry [ˈfaundri] *n.* 铸造，铸造类；铸造厂
moisture [ˈmɔistʃə(r)] *n.* 水分
drag moulding flask 下模砂箱
ram [ræm] *vt.* 夯实
clearance [ˈkliərəns] *n.* 空隙
drag [dræg] *n.* 下砂箱
compact [kəmˈpækt] *vt.* & *vi.* 压紧，使坚实
vent wire 通气针
dowel pins 定位销
cope flask 上砂箱
sprue [spruː] *n.* 注入口，铸口
pouring basin 浇注槽
bellows [ˈbeləuz] *n.* 风箱
core print 型芯座
warpage [ˈwɔːpeidʒ] *n.* 翘曲，弯曲，扭曲
plywood [ˈplaiwud] *n.* 夹板，胶合板

veneer [vəˈniə(r)] *n.*	胶合板的一层薄木片
contour [ˈkɔntuə(r)] *n.*	轮廓
durability [ˌdjurəˈbiləti] *n.*	耐久性；耐用年限
corrosion [kəˈrəuʒ(ə)n] *n.*	腐蚀
shrinkage allowances	收缩留量; 收缩容许量
clay [klei] *n.*	黏土；泥土
epoxy resin	环氧树脂
lead [liːd] *n.*	铅
polyurethane [ˌpɔliˈjuərəθein] *n.*	聚氨酯；聚亚安酯
thermosetting [ˈθəːməusetiŋ] *adj.*	热固的；热硬化性的
synthetic resin	合成树脂; 人造树脂
phenol [ˈfiːnɔl] *n.*	石碳酸，苯酚
formaldehyde [fɔrˈmældihaid] *n.*	甲醛
methylene [ˈmeθiliːn] *n.*	亚甲基
tetramine [ˈtetrəmain] *n.*	羟化四甲铵
curing [ˈkjuəriŋ] *n.*	固化；硬化
investment casting	熔模铸造
expendable [ikˈspendəb(ə)l; ek-] *adj.*	排出的；不重复使用的
cluster [ˈklʌstə] *n.*	群；簇
slurry [ˈslʌri] *n.*	泥浆；悬浮液
ceramic [siˈræmik] *adj.*	陶瓷的
ethyl silicate	硅酸乙酯
sodium silicate	硅酸钠; 水玻璃
fused silica	熔融石英; 石英玻璃
zircon [ˈzəːkɔn] *n.*	锆石
ceramic coating	陶瓷涂层
binder [ˈbaində(r)] *n.*	黏合剂
borne [bɔːn] *v.* (bear 的过去分词)	承担；承受
graphite [ˈgræfait] *n.* & *vt.*	石墨；黑铅用石墨涂（或搀入等）
magnesium [mægˈniːziəm] *n.*	镁
furnace [ˈfəːnis] *n.*	火炉，熔炉
blister [ˈblistə(r)] *n.*	气泡；砂眼
porosity [pɔːˈrɔsəti] *n.*	有孔性，多孔性
wrought [rɔːt] *adj.*	锻造的；加工的；精细的
crucible [ˈkruːsib(ə)l] *n.*	坩埚
centrifugal [ˌsentriˈfjuːgl] *adj.*	离心的
ingot [ˈiŋgət] *n.*	锭；铸块
recrystallization [riːˌkristəlaiˈzeiʃən] *n.*	再结晶，再结晶作用
crystal [ˈkristl] *n.*	结晶，晶体

nucleate [ˈnjuːklieit] *v.*	(使) 成核
deformation [ˌdiːfɔːˈmeiʃ(ə)n] *n.*	变形
Tin [tin] *n.*	锡
Beryllium [bəˈriliəm] *n.*	铍
Molybdenum [məˈlibdənəm] *n.*	钼
Tantalum [ˈtæntələm] *n.*	钽
Tungsten [ˈtʌŋst(ə)n] *n.*	钨
coalescence [ˌkəuəˈlesns] *n.*	合并；联合；接合
configuration [kənˌfigəˈreiʃn] *n.*	构造；结构；外形
extrusion [ikˈstruːʒn] *n.*	挤出；推出；喷出
cylinder [ˈsilində(r)] *n.*	圆筒；汽缸
container [kənˈteinə] *n.*	集装箱；容器
dummy block	(在活塞与热金属之间的) 挤压垫
rod [ˈrɔd] *n.*	竿；杆
conical [ˈkɔnikl] *adj.*	圆锥的；圆锥形的
reel [riːl] *n.*	卷轴；卷盘；卷筒
tensile [ˈtensail] *adj.*	拉力的；可伸展的；拉伸
pickling [ˈpikliŋ] *n.*	酸洗；浸酸
sulling [ˈsʌliŋ] *n.*	黄化；氧化表层
phosphating [ˈfɔsfeitiŋ] *n.*	磷化处理
liming [ˈlaimiŋ] *n.*	加石灰，撒石灰
mandrel [ˈmændrəl] *n.*	(圆形) 心轴
seamless [ˈsiːmlis] *adj.*	无缝的；无伤痕的
embossing [imˈbɔsiŋ] *n.*	压纹；压花；模压加工
bolt [bəult] *n.*	螺栓
screw [skruː] *n.*	螺钉
rivet [ˈrivit] *n.*	铆钉
adhesive bonding	附着黏合
brazing [ˈbreiziŋ] *n.* & *v.*	钎焊；铜焊；用锌铜合金钎接
soldering [ˈsɔldəriŋ] *n.*	软焊；低温焊接；热焊接
disassemble [ˌdisəˈsembl] *vt.*	解开，分解
disfigure [disˈfigə(r)] *vt.*	使变丑；损毁……的外形
brake shoe linings	制动蹄衬片
damping [ˈdæmpiŋ] *n.*	阻尼
elastomer [iˈlæstəmə(r)] *n.*	弹性体，人造橡胶
acetylene [əˈsetiliːn] *n.*	乙炔；电石气
cathode [ˈkæθəud] *n.*	阴极
anode [ˈænəud] *n.*	阳极
current [ˈkʌrənt] *n.*	电流；水流；涌流

ionized [ˈaiənˌaiz] *adj.*	电离的；已电离的
plasma [ˈplæzmə] *n.*	等离子体
trench [trentʃ] *n.*	沟，沟渠
shielded [ˈʃi:ldid] *adj.*	隔离的；屏蔽了的；防护的
shielded metal-arc welding	气保护金属极电弧焊
coated electrode	涂剂焊条
stick electrode	手工焊条
impurity [imˈpjuərəti] *n.*	杂质
inert-gas	惰性气体
homogeneous [ˌhɔməˈdʒi:niəs] *adj.*	同性质的，同类的
Helium [ˈhi:liəm] *n.*	氦
Argon [ˈɑ:gɔn] *n.*	氩
Hydrogen [ˈhaidrədʒən] *n.*	氢
thoria [ˈθɔ:riə] *n.*	氧化钍
zirconia [zə:ˈkəuniə] *n.*	氧化锆
flux-cored arc welding	药芯焊丝电弧焊
spatter [ˈspætə(r)] *n.*	喷溅；飞溅
atomic hydrogen welding	原子氢焊
plasma arc welding	等离子弧焊
stud arc welding	螺柱电弧焊
fire cracker welding	躺焊
amperage [ˈæmpəridʒ] *n.*	安培数；电流强度

Unit 10

lathe [leið] *n.*	车床，机床
drilling [ˈdriliŋ] *n.*	钻孔
boring [ˈbɔ:riŋ] *n.*	镗孔
milling [ˈmiliŋ] *n.*	铣削
grinding [ˈgraindiŋ] *n.*	磨削
planing [pleiniŋ] *n.*	龙门刨削
gear [giə] *n.*	齿轮
sawing [ˈsɔ:iŋ] *n.*	锯割
rotary [ˈrəutəri] *adj.*	旋转的，转动的
bench lathe	台式车床
tool room lathe	工具车床
copying lathe	仿形车床，靠模车床
gap bed lathe	马鞍形车床，凹口车床
hollow [ˈhɔləu] *adj.*	空的；中空的
spindle [ˈspind(ə)l] *n.*	轴

hollow spindle lathe	空心轴车床
capstan and turret lathes	六角刀架车床
mount ['maunt] *v.*	安装
accessory [æk'sesəriz] *n.*	附件；辅助程序
axis of revolution	旋转轴，回转轴
radius ['rediəs] *n.*	半径，半径范围
knurling ['nə:liŋ] *n.*	滚花，压花纹
serration [se'reiʃn] *n.*	锯齿；锯齿状突起
deform [di'fɔrm] *vt.*	使……变形
gripping surface	攫取面，抓取面
parting ['pɑ:tiŋ] *n.*	分离，分开，断裂
plunge cut	全面进给，横向进给
sever ['sevə] *vt. & vi.*	割断，断裂
groove [gru:v] *n.*	凹槽
quill [kwil] *n.*	管
tailstock ['teilstɔk] *n.*	车床的尾座
counter sinking	锪锥形沉孔
counter boring	锪孔
square [skweə] *adj. & n.*	成直角的；平方的
idle ['aid(ə)l] *adj.*	停顿的；空转的
reciprocating [ri'siprəkeitiŋ] *adj.*	往复的
shaper ['ʃeipə] *n.*	牛头刨床
planer ['pleinə(r)] *n.*	龙门刨床
slotter ['slɔtə] *n.*	立刨床
ram [ræm] *n.*	滑枕
cutting stroke	割削冲程；刨程
swivel ['swiv(ə)l] *vt. & vi.*	使旋转；旋转
overhang [əuvə'hæŋ] *n.*	突出部分；悬垂部分
flank [flæŋk] *n.*	侧面
clapper box	抬刀座，抬刀装置
angular ['æŋgjulə] *adj.*	有角度的；倾斜的
convex ['kɔnveks] *adj.*	凸面的；凸状的
concave ['kɔnkeiv] *adj.*	凹的，凹面的
reciprocate [ri'siprəkeit] *v.*	直线往复运动
stationary ['steiʃ(ə)n(ə)ri] *adj.*	固定的；静止的
hydraulically [hai'drɔ:lik] *adj.*	液压的，水压的
keyway ['ki:wei] *n.*	键槽
spline [splain] *n.*	花键
shank [ʃæŋk] *n.*	柄；杆件

tolerance [ˈtɔl(ə)r(ə)ns] *n.*	公差
duplex [ˈdju:pleks] *adj.*	双重的
triplex [ˈtripleks] *adj.*	三重的
plano [ˈpleinən] *adj.*	平的
spline shaft milling machines	花键轴铣床
clamping [klæmpiŋ] *v.*	夹住；夹紧
string milling	连续铣削
abreast [əˈbrest] *adj.*	并排的
gang milling	排铣，多刀铣削
arbour [ˈɑ:bə] *n.*	刀架
slab [slæb] *n.*	平板
straddle milling	跨铣，用两把铣刀片同时加工
reaming [ˈri:miŋ] *n.*	铰孔
tapping [tæpiŋ] *n.*	攻螺纹
flute [flu:t] *n.*	（圆柱上的）凹槽
stub [stʌb] *n.*	台柱
stub arbor	短心轴
spade [speid] *adj.*	铲形的
spade drill	平钻，扁钻；扁平钻
blade [bleid] *n.*	刀片
bevel [ˈbev(ə)l] *n.*	斜角；斜面
titanium nitride	氮化钛
gun drilling	深钻孔
coolant [ˈku:lənt] *n.*	冷却液
brazed [breizd] *adj.*	铜焊的
burnishing [ˈbə:niʃiŋ] *n.*	抛光
alignment [əˈlainm(ə)nt] *n.*	校准
reamer [ˈri:mə(r)] *n.*	铰制；铰刀
chamfer [ˈtʃæmfə] *n.*	斜面；凹槽
brass [brɑ:s] *n.*	黄铜
bronze [brɔnz] *n.*	青铜
commensurate [kəˈmenʃ(ə)rət; -sjə-] *adj.*	相等的；相称的；相当的
regrinding [regˈraindiŋ] *n.*	再次研磨
automatically [ˌɔ:təˈmætikli] *adv.*	自动地；机械地
copious [ˈkəupiəs] *adj.*	足够的
abrasive [əˈbresiv] *n.*	研磨
deburr [di:ˈbə:] *vi.*	清理毛刺
honing [ˈhəuniŋ] *n.*	珩磨
lapping [ˈlæpiŋ] *n.*	研磨；抛光

grit [grit] *n.*	细沙，砂砾
transverse [trænz'və:s; trɑ:nz-; -ns-] *adj.*	横向的
plunge grinding	横磨
out-of-roundness	不圆度
crest [krest] *n.*	波峰，高点
refinement [ri'fainmənt] *n.*	提高；改善
abrasion [ə'breiʒn] *n.*	磨损
fragmentation [ˌfrægmen'teiʃn] *n.*	裂痕
symmetrical [si'metrikl] *adj.*	匀称的，对称的
glossy ['glɔsi] *adj.*	光滑的；有光泽的
polishing ['pɔliʃiŋ] *n.*	抛光；磨光
cushion ['kuʃn] *v.*	起缓冲作用
smeared [smiəd] *adj.*	弄脏的
contour ['kɔntuə(r)] *n.*	轮廓
retract [ri'trækt] *v.*	拉回，缩回

Unit 11

curriculum [kə'rikjuləm] *n.*	课程
hazardous ['hæzədəs] *adj.*	有危险的；冒险的
in contrast to	与……形成对照
disastrous [di'zɑ:strəs] *adj.*	灾难性的；损失惨重的
hatred ['heitrid] *n.*	憎恨；怨恨；敌意
adhere to	坚持；黏附；拥护，追随
implement ['impliment] *n. & v.*	实施，执行；实现
die-casting mould	压铸模具
trim [trim] *vt. & vi. &* n.	修剪；整理；削减；修剪；整齐
buffing ['bʌfiŋ] *n.*	磨光，抛光
armature ['ɑ:mətʃə; -tj (u) ə] *n.*	电枢（电动机的部件）；盔甲
reprogrammable [rip'rəugræməbl] *adj.*	可改编程序的；可重复编程的
retrieval [ri'tri:vl] *n.*	检索；恢复；取回
faulty ['fɔlti] *adj.*	有错误的；有缺点的
terrain [tə'rein] *n.*	地形；领域；地势
trembling [trembliŋ] *n. & adj. & v.*	发抖的；哆嗦的；颤抖
array [ə'rei] *n. & vt.*	数组，阵列；大批；排列，列阵
thumb rule	经验法则；计算中近似法
miserable ['miz(ə)rəb(ə)l] *adj.*	悲惨的；痛苦的；卑鄙的
paramount ['pærəmaunt] *adj. &* n.	最重要的，主要的
legislation [ledʒis'leiʃ(ə)n] *n.*	立法；法律
positional [pə'ziʃənəl] *adj.*	位置的；地位的

seam welding	缝焊
turntable [ˈtəːnteib(ə)l] *n.*	转盘；转车台；转车
configuration [kənˌfiqjəˈreʃən] *n.*	配置；结构；外形
orientation [ˌɔːriənˈteiʃn] *n.*	方向；定向；适应；情况介绍
Cartesian [kɑːˈtiːziən] *adj. & n.*	笛卡儿哲学的；笛卡儿的
cylindrical [siˈlindrikəl] *adj.*	圆柱形的；圆柱体的
spherical [ˈsferik(ə)l] *adj.*	球形的，球面的
articulate [ɑːˈtikjuleit] *vt. & vi.*	用关节连接
rectangular [rekˈtæŋgjulə] *adj.*	矩形的；成直角的
Cartesian coordinate system	笛卡儿坐标系
rigid structure	刚性结构
rotary [ˈrəut(ə)ri] *adj. & n.*	旋转的；轮流的；旋转式机器
prismatic [prizˈmætik] *adj.*	棱柱的，棱镜的
prismatic joints	移动副
elevation [ˌeliˈveiʃ(ə)n] *n.*	高地；海拔；提高；正面图
gantry robot	高架式机器人；桁架机器人
pneumatic [njuːˈmætik] *adj. & n.*	气动的；充气的；气胎
hydraulic [haiˈdrɔlik] *adj.*	液压的；水力的；水力学的
payload [ˈpeiləud] *n.*	（导弹、火箭等的）有效载荷
servo-controlled	伺服控制的
microprocessor [maikrə(u)ˈprəusesə] *n.*	微处理器
monitor [ˈmɔnitə] *n. & vt.*	监视器；监听器；监控
utilize [ˈjutəlaiz] *vt.*	利用
pendant [ˈpend(ə)nt] *n.*	下垂物，垂饰
taction [ˈtækʃən] *n.*	触摸；接触
proximity [prɔkˈsimiti] *n.*	接近，邻近；接近
potentiometer [pə(u),tenʃiˈɔmitə] *n.*	电位计；分压计
tacho-generators [ˌtækəuˈdʒenəreitə] *n.*	测速传感器；测速发电机
encoder [enˈkəudə] *n.*	编码器；译码器
grating line	光栅线
light sensitive cell	光敏细胞
gray scale	灰度；灰阶
binary bit	二进制
potentiometer [pə(u),tenʃiˈɔmitə] *n.*	电位计；分压计
displacement transducer	位移传感器
synchro [ˈsiŋkrəu] *adj. & n.*	同步的；同步机
resolver [riːˈzɔlvə] *n.*	分解器
voltage [ˈvəultidʒ；ˈvɔltidʒ] *n.*	电压
hamper [ˈhæmpə] *vt. & n.*	妨碍；束缚；阻碍物

gauge [geidʒ] *n. & vt.*	计量器；标准尺寸；测量
scale pan	天平盘；秤盘
strain gauge	应变仪；变形测量器
wire [waiə] *n. & vt. & vi.*	电线；金属丝；电报
foil [fɔil] *vt. &n.*	衬托；阻止；挫败；箔
etch [etʃ] *vt. & vi. & n.*	蚀刻；刻蚀；腐蚀剂
piezoelectric [piːˌeizəuiˈlektrik] *adj.*	压电的
quartz [kwɔːts] *n.*	石英
tourmaline [ˈtuəməlin; -liːn] *n.*	电气石
Rochalle salt	罗谢尔盐
switch off	(用开关) 关掉；切断 (电源)
inductive [inˈdʌktiv] *adj.*	归纳的；感应的；诱导的
capacitive [kəˈpæsitiv] *adj.*	电容性的
oscillator [ˈɔsileitə(r)] *n.*	振荡器；摆动物
amplitude [ˈæmplitjuːd] *n.*	振幅
dielectric [daiiˈlektrik] *adj. & n.*	非传导性的；绝缘体
insulator [ˈinsjuleitə] *n.*	绝缘体
coverage [ˈkʌv(ə)ridʒ] *n.*	覆盖，覆盖范围
parameter [pəˈræmitə] *n.*	参数；系数；参量
pixel [ˈpiksl] *n.*	像素
hardware [ˈhɑːdweə] *n.*	计算机硬件
lens [lenz] *n.*	透镜，镜头
synchronisation [ˌsiŋkrənaiˈzeiʃən] *n.*	同步；同时发生
remedy [ˈremədi] *n.*	救济方法
vidicon camera	视像管摄像机
astronomical [æstrəˈnɔmik(ə)l] *adj.*	天文的，天文学的；极大的
interpretation [intəːpriˈteiʃ(ə)n] *n.*	解释；翻译
robust [rə(u)ˈbʌst] *adj.*	强健的；健康的
stringent [ˈstrin(d)ʒ(ə)nt] *adj.*	严格的；严厉的；短缺的
resolution [rezəˈluːʃ(ə)n] *n.*	分辨率；决议；解决
reliability [riˌlaiəˈbiləti] *n.*	可靠性
inoperative [inˈɔp(ə)rətiv] *adj.*	不起作用的；无效力的

附录二 国际机械工程相关学术组织中英（外）文名称对照（部分）

中文名称	英（外）文名称
国际组织	
国际机械工程学会联合会（ICOMES）	International Congress of Mechanical Engineering Societies
国际热处理与表面工程联合会（IFHTSE）	International Federation for Heat Treatment and Surface Engineering

（续）

中文名称	英（外）文名称
国际组织	
太平洋地区焊接组织联合会（POCWA）	Pacific Ocean Coalition of Welding Associations
国际压力容器理事会（ICPVT）	International Council of Pressure Vessel Technology
世界铸造者组织（WFO）	World Foundrymen Organization
国际机器理论与机构学联合会（IFToMM）	International Federation for the Theory of Machines
国际焊接学会（IIW）	International Institute of Welding
国际无损检测委员会（ICNDT）	The International Committee for Non-Destructive Testing
国际摩擦学理事会（ITC）	International Tribology Council
电气和电子工程师协会（IEEE）	Institute of Electrical and Electronics Engineers
亚太地区无损检测委员会（APCNDT）	Asian Pacific Committee on Non-Destructive Testing
德国	
德国工程师学会	Verein Deutscher Ingenieure
德国无损检测学会	Deutsche Gesellschaft fuer Zerstoerungsfreie Pruefung e. V.
德国焊接学会	Deutscher Verband fuer Schweisstechnik e. V.
德国机械设备制造协会热过程和废物处理技术分会	Verband Deutscher Maschinen und Anlagenbau e. V. Fachgemeinschaft Thermo Prozess und Abfalltechnik
德国机械设备制造协会	Verband Deutscher Maschinen und Anlagenbau e. V.
美国	
美国机械工程师学会	American Society of Mechanical Engineers
美国制造工程师学会	Society of Manufacturing Engineers
美国焊接学会	American Welding Society
日本	
日本机械学会	Japan Society of Mechanical Engineers
日本摩擦学工作者学会	Japanese Society of Tribologists
日本无损检测学会	Japanese Society for Nondestructive Inspection
日本物流协会	Japanese Materials Handling Society
日本物流系统机器协会	The Japan Institute of Material Handling
日本工业成像协会	Japan Industrial Imaging Association
俄罗斯	
俄罗斯机械工程师学会	Russian Society of Mechanical Engineers
俄罗斯无损检测和技术诊断学会	Russian Society for Nondestructive Testing and Technical Diagnostics
俄罗斯摩擦学委员会	Russian Committee of Tribology
韩国	
韩国无损检测学会	Korean Society for Nondestructive Testing
韩国机械工程师学会	Korean Society of Mechanical Engineers
韩国熔接工业协同组合	Korea Welding Industry Cooperative
英国	
英国机械工程师学会	Institution of Mechanical Engineers
英国工程技术学会	The Institution of Engineering and Technology
英国营运工程师学会	The Society of Operations Engineers

（续）

中文名称	英（外）文名称
印度	
印度无损检测学会	Indian Society for Nondestructive Testing
印度机械工程师学会	Institution of Mechanical Engineers, India
其他国家	
匈牙利机械工程师学会	Hungarian Scientific Society of Mechanical Engineers
波兰机械工程师学会	Polish Society of Mechanical Engineers and Technicians
菲律宾机械工程师学会	Philippine Society of Mechanical Engineers
巴基斯坦工程师学会	Institution of Engineers Pakistan
越南机械工程学会	Vietnamese Association of Mechanical Engineering
巴西无损检测学会	Brazilian Association of Nondestructive Testing
以色列机械工程师学会	Society of Mechanical Engineers in Israel
法国机械学会	Association Francaise De Mecanique
新加坡焊接学会	Singapore Welding Society
希腊机械电气工程师学会	Hellenic Association of Mechanical and Electrical Engineers
爱尔兰工程师学会	The Institution of Engineers of Ireland
塞浦路斯机械工程师学会	Cyprus Mechanical Engineers Association
阿尔巴尼亚机械工程学会	Albanian Society of Mechanical Engineers
埃及机械工程师学会	Egyptian Society of Mechanical Engineers
加拿大机械工程师学会	Canadian Society for Mechanical Engineering
瑞典机械造船和航空工程师学会	Swedish Society of Mechanical Engineers, Naval Architects & Aeronautical Engineers
孟加拉工程师学会	Institution of Engineers, Bangladesh
澳大利亚工程师学会	The Institution of Engineers Australia
澳大利亚无损检测学会	Australian Institute for Nondestructive Testing
白俄罗斯无损检测学会	The Belarusian Association on Nondestructive Testing and Technical
哈萨克斯坦国无损检测与有损检测协会	NDT&TD Association Republic of Kazakhstan

附录三　机械工程相关学术会议（部分）

一、国际机构组织会议

会议名称	所属学科	主办单位
IEEE 国际控制科学与系统工程会议/IEEE International Conference on Control Science and Systems Engineering (ICCSSE)	运筹学与控制论；自动控制理论与技术；自动化技术应用；控制系统仿真技术；机械制造与机床技术	南洋理工大学电子与电气工程学院
IEEE 机械与航空工程国际会议/IEEE International Conference on Mechanical and Aerospace Engineering (ICMAE)	空间科学；金属材料；自动控制理论与技术；仪器仪表与装置；机械学	Embry Riddle Aeronautical University, UK

（续）

会议名称	所属学科	主办单位
IEEE 机电一体化与自动化国际会议/IEEE International Conference on Mechatronics and Automation (ICMA)	生物医学工程学；自动控制理论与技术；自动化技术应用；机器人；机械学	IEEE Robotics and Automation Society，哈尔滨工业大学，日本香川大学
国际仿生工程学术会议/ International Conference of Bionic Engineering (ICBE)	流体力学；人工智能；纳米科学与技术；复合材料；机械学	国际仿生工程学会（ISBE）
世界铸造会议/ World Foundry Congress	金属材料；材料加工与处理；机械制造与机床技术；材料成形制造与设备	世界铸造组织
IEEE 先进机器人与社会发展研讨会/ IEEE Workshop on Advanced Robotics and Its Social Impacts	控制系统仿真技术；机器人；机械制造与机床技术	IEEE 机器人与自动化学会（IEEE RAS）
纳米工程学：制造，性能，光学和设备国际会议/Nanoengineering: Fabrication, Properties, Optics, and Devices	光学；纳米科学与技术；专用机械	国际光学工程学会
电气与电子工程，通信工程和机电一体化国际会议/The Second International Conference on Electrical and Electronic Engineering, Telecommunication Engineering, and Mechatronics (EEETEM)	电子工程；电工；电力电子；通信技术	University of Salford
设计自动化会议/Annual Design Automation Conference	计算机软件；计算机应用技术；自动化技术应用；控制系统仿真技术	美国计算机学会
IEEE/ RSJ 智能机器人与系统国际会议/IEEE/RSJ International Conference on Intelligent Robots and Systems	计算机系统结构与硬件；人工智能；控制系统仿真技术；机器人	Korea Institute of Machinery & Materials (KIMM), Korea Aerospace Research Institute (KARI), Korea Atomic Energy Research Institute (KAERI), Korea Advanced Institute of Science and Technology (KAIST)

二、国内机构组织会议

会议名称	所属学科	主办单位
中国（国际）光整加工技术学术会议/International Conference on Surface Finishing Technology and Surface Engineering (ICSFT)	光学；光电子学；机械制造与机床技术	中国机械工程学会生产工程分会光整加工专业委员会
国际先进光学设计与制造技术交流会/Advanced optical design and manufacturing technologies	光学；光电子学；机械制造与机床技术	中国光学工程学会
亚洲热处理及表面工程国际会议/Asian Conference on Heat Treatment and Surface Engineering	机械制造与机床技术；材料成形制造与设备	中国机械工程学会热处理分会、日本热处理学会、韩国热处理学会

（续）

会议名称	所属学科	主办单位
表面工程国际会议/International Conference on Surface Engineering	材料科学基础学科；材料加工与处理；机械制造与机床技术	中国机械工程学会表面工程分会
全国涂料涂装及表面保护会议/National Paint & Coating and Surface Protection Conference	材料科学基础学科；材料加工与处理；机械学；机械制造与机床技术	中国腐蚀与防护学会涂料涂装与表面保护专业委员会
全国表面工程大会/National Conference on Surface Engineering	机械学；机械制造与机床技术	中国机械工程学会表面工程分会
微试样测试技术国际学术会议/International Conference of Small Sample Test Techniques	仪器仪表与装置；机械学	中国机械工程学会
国际汽车变速器及驱动技术研讨会/TM Symposium China-ICE，HEV and EV Transmissions and Drives（TMC）	自动化技术应用；控制系统仿真技术；机械学	中国汽车工程学会
国际光电技术与应用创新研讨会/The International Symposium on Innovative Photoelectronic Technology and Application（IPTA）	光电子学；机械制造与机床技术	国际光学工程学会（SPIE）、美国光学学会（OSA）、中国光学工程学会
中国国际压铸会议/China International Diecasting Congress &Exhibition	金属材料；材料加工与处理；材料成形制造与设备	中国机械工程学会
中国机器人焊接学术与技术交流会议/Chinese Conference on Robotic Welding（CCRW）	机器人；机械制造与机床技术；材料成形制造与设备	中国焊接学会机器人与自动化专委会、中国焊接协会汽车专委会、中国焊接熔焊工艺与设备专委会、中国焊接学会压力焊专委会
全国疲劳与断裂学术会议/National Conference on Fatigue and Fracture	一般力学与力学基础；固体力学；材料科学基础学科；机械学	中国机械工程学会、中国材料研究学会、中国航空学会、中国金属学会、中国力学学会、中国腐蚀与防护学会
国际机器人感知与控制技术研讨会/International Conference on Robot Sensing and Advanced Control	光电子学；控制系统仿真技术；机器人	中国光学工程学会
全国流体传动与控制学术会议/Fluid Power Transmission & Control Conference of China	流体力学；动力机械工程	中国机械工程学会流体传动与控制分会
材料物理模拟与数值模拟国际学术会议/International Conference on Physical and Numerical Simulation of Materials Processing	材料科学基础学科；控制系统仿真技术；机械制造与机床技术	哈尔滨工业大学及焊接国家焊接重点实验室

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